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A muzzle device to suppress the secondary muzzle flash from a GAU8/A Mann barrel was developed. Its effectiveness as a seven-barrel device on a flying GAU8/A gun system was estimated through computer analysis and was examined in experimental simulations using lightweight projectiles and various propellant/flash suppressant salt combinations.

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FINAL TECHNICAL REPORT, 14 Sep 76-18 Mar 77,

on

THE DEVELOPMENT OF A MUZZLE DEVICE TO SUPPRESS THE SECONDARY MUZZLE FLASH ON THE GAU8/A GUN SYSTEM

to

GENERAL ELECTRIC COMPANY
BURLINGTON, VERMONT

18 Mar[redacted]77

by

Joseph E. Backofen, Jr

60p.

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TABLE OF CONTENTS

LIST OF TABLES

TABLE OF CONTENTS
(Continued)

Page

LIST OF TABLES
(Continued)

LIST OF FIGURES

TABLE OF CONTENTS
(Continued)

Page

LIST OF FIGURES
(Continued)

TABLE OF CONTENTS
(Continued)

Page

LIST OF FIGURES
(Continued)

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Mr. Wayne Hathaway and Mr. William Walton of the General Electric Company, Burlington, Vermont, served as technical monitors on this program. Their assistance in expediting the delivery of the propellants and ammunition that were used on this intensive program is greatly appreciated. Several persons on the Battelle staff also made valuable contributions to this program. Worthy of mention are Dr. Joe H. Brown, Jr., for managerial support, Mr. A. S. Chace and Mr. W. F. Schola for assistance in the conduct of the secondary muzzle flash experiments, and Mrs. B. J. Bullinger for the typing of this and all the other program reports.

FINAL TECHNICAL REPORT

on

THE DEVELOPMENT OF A MUZZLE DEVICE TO SUPPRESS THE SECONDARY MUZZLE FLASH ON THE GAU8/A GUN SYSTEM

to

GENERAL ELECTRIC COMPANY
BURLINGTON, VERMONT

from

BATTELLE
Columbus Laboratories

by

Joseph E. Backofen, Jr.

March 18, 1977

SUMMARY

An intensive program was conducted from September 15, 1976 to March 15, 1977 to develop a muzzle device to suppress the secondary muzzle flash from a GAU8/A Mann barrel and a rationale to scale its effectiveness up to a seven-barrel device on a flying GAU8/A gun system. The interior ballistics and secondary flash performance of two propellants used in the GAU8/A were modelled by Battelle's "Brief Interior Ballistics Computer Program For Preliminary Gun Design and Prediction of Secondary Muzzle Flash".(1)* The performance of the propellants and the muzzle device were extrapolated by using the computer program in order to predict the performance of a seven-barrel device at aircraft flight conditions and the relationship to the experimental data base.

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* References are given at the end of the report.

BACKGROUND OF THE PROBLEM

When the GAU8/A gun system was first flight-tested, severe secondary muzzle flash occurred when the gun was fired at the highest rate of fire; and this led to sustained secondary burning and flashing (SSBF). Preliminary attempts to control the secondary ignition of the muzzle gases by means of mechanical devices were only partially successful.[2] Chemical flash suppressants were also utilized to suppress the secondary muzzle flash, but the amounts of suppressive salts utilized led to the formation of smoke and soot.[2] This residue gets ingested into the engine and the airframe as well as deposited on the pilot's windshield. It is a nuisance and causes the use of a windshield washer, an increased engine cleaning, and possibly an airframe corrosion problem.

To seek relief from the problems of smoke and soot, the U.S. Air Force A-10 Systems Project Office, through General Electric Company, Burlington, Vermont, advertised in the Commerce Business Daily of April 19, 1976 (Issue No. PSA-6555) for sources to "Examine the Effects of the Capabilities of Different Propellants and Chemical Muzzle Flash Suppressants on Gun Interior Ballistics, Muzzle Flash, and Aircraft Materials Corrosion". As a result of Battelle's response to this advertisement, Battelle received a copy of General Electric RFP No. FDA-050676, "Propellant Reformulation Program". Battelle's response was to submit an alternative proposal to develop a mechanical muzzle device. Battelle received an award, and this final report documents the results of the program.

OBJECTIVE AND APPROACH

The objective of this research program was to develop a muzzle device and evaluation procedure to suppress secondary muzzle flash on the GAU8/A gun system with a minimum amount of chemical flash suppressant salts in the propellant charge.

The approach to the problem was detailed into the following five tasks, which were completed within the program:

Task 1. Propellant compositions with varying levels of suppressant salt content were evaluated by means of the computer program to determine the thresholds for secondary muzzle flash at both ground and flight conditions.

Task 2. Computer predictions were compared to gun experiments conducted at Battelle's West Jefferson facility for the on-the-ground conditions as well as gun parameter scaled (different projectile weights) simulated flight conditions.

Task 3. The muzzle device was designed and fabricated for use on the GAU8/A Mann barrel.

Task 4. DuPont (8601) and Hercules (HC-25-B, lot 021) propellant compositions supplied by General Electric were fired with varying concentrations of suppressant salts at ground conditions to determine the effectiveness of the combinations of suppressant salt and the muzzle device.

Task 5. The results of the empirical investigations of Task 4 were analytically scaled to project the effectiveness of the muzzle device design on the propellants and the gun system at flight conditions.

TECHNICAL DISCUSSION

Computer Analysis and Prediction of Muzzle Flash

The detailed progress achieved during each month of the program has been documented in five monthly progress reports having the same title as this final report. This final report describes the overall trend of the program, the significant findings, and the accomplishment of the program tasks.

During the initial period of the program, Battelle's computer program[1] was used to evaluate the temperatures T_3 and T_5, described by Carfagno in "Handbook on Gun Flash"[3], that would be expected for DuPont and Hercules propellants used in T.P. ammunition fired from a flying gun. The computer printouts were run for varying concentrations of suppressant salts, and the flash sensitivity of the combinations were noted. The reproduction of the temperatures, T_3 and T_5, on the ground could be accomplished by two methods: decreasing the projectile weight or reducing the length of the barrel.

Table 1 illustrates the temperatures T_{3max} and T_{5max} that are predicted by the computer program for Hercules propellant wherein the ballistic cycle of the propellant has been matched to experimental records of pressure/time and muzzle velocity for the three bullet weights and the 86-inch barrel. As this table shows, the initial temperatures for the 0.80-lb projectile are below those to be expected for the flight condition. The flight condition temperatures T_3, T_5 could be exceeded by either reducing the bullet weight or by shortening the barrel. Since the program was to examine several propellant and suppressant salt compositions, it was decided that the best method to use was that of reducing the projectile weight. Furthermore, the reduction of the projectile weight would permit a means to overtest the muzzle device by firing very lightweight projectiles.

Since the experimental portion of the program was being conducted outdoors and winter was approaching, the computer program was also used to examine the effects of decreasing ambient temperatures on the occurrence of secondary flash. Table 2 shows the very small variations in T_{3max}/T_{5max} that were to be expected over the range of air temperatures during which the experiments were conducted. On the basis of these computer predictions, it was decided that the effect of ground testing air temperature over the range from 32 to -10 °F would contribute an insignificant amount of error to the experimental results.

The computer program was also used to examine the variation in the temperatures T_3 and T_5 with an assumed increasing air/gun gas stagnated mixture temperature at flight conditions in an attempt to determine the performance required from the muzzle device toward creating a shockless and/or turbulent mizing flow. Figure 1 illustrates these computer predictions for DuPont propellant and a 0.80-lb projectile for variations in the ambient air/gas temperature and different concentrations of suppressant salt. From this computer analysis, it was determined that the muzzle device really had to perform more than the normal function of trying to expand the gases without shocks because T_3, the mixed shockless flow temperature, approached the T_{5max}, shocked flow temperature. The particular significance of the figure and analysis is that a 2.0 percent concentration of suppressant salt was found to be required to suppress SSBF during aircraft flight after 8 to 10

TABLE 1. VARIATION OF THE TEMPERATURES T_{5max} AND T_{3max} AS A FUNCTION OF BARREL LENGTH AND PROJECTILE WEIGHT FOR 150 GRAMS OF HERCULES PROPELLANT WITH 0.5 PERCENT KNO_3 (HC-25-B)

(IBAL PREDICTIONS)

Projectile Weight, Lb	Barrel Length, In. 86	80	74	68
	T_{5max}, T_{3max} (°K)			
.80	1092, 937	1099, 943	1107, 949	1116, 956
.74	1112, 953	1119, 958	1127, 965	1136, 972
.70	1127, 965	1135, 971	1143, 977	1152, 984

(Pa = 14.696 psi, Ta = 273.2 °K (32 °F), Ground Type Conditions)

NOTE: For flight type conditions of Pa = 17.696 psi, Ta = 300.0 °K (80 °F), a charge of 150 grams of Hercules powder and bullet weight of 0.80 lb fired from the 86-inch barrel yield T_{5max} = 1101 °K and T_{3max} = 953 °K.

TABLE 2. VARIATION IN TEMPERATURES T_{5max} AND T_{3max} FOR CHANGES IN AMBIENT TESTING TEMPERATURE FOR AMMUNITION RELOADED WITH 150 GRAMS OF HC-25-B PROPELLANT.

	Projectile Weight					
	0.80	0.74	0.70	0.64	0.60	0.55
Air Temperature	T_{5max}, T_{3max} (°K)					
32 °F	1092/937	1112/953	1128/965	1154/986	1175/1002	1203/1024
0 °F	1091/930	1111/946	1127/959	1153/979	1174/995	1203/1018
-10 °F	1090/928	1111/944	1127/957	1153/977	1173/993	1202/1016

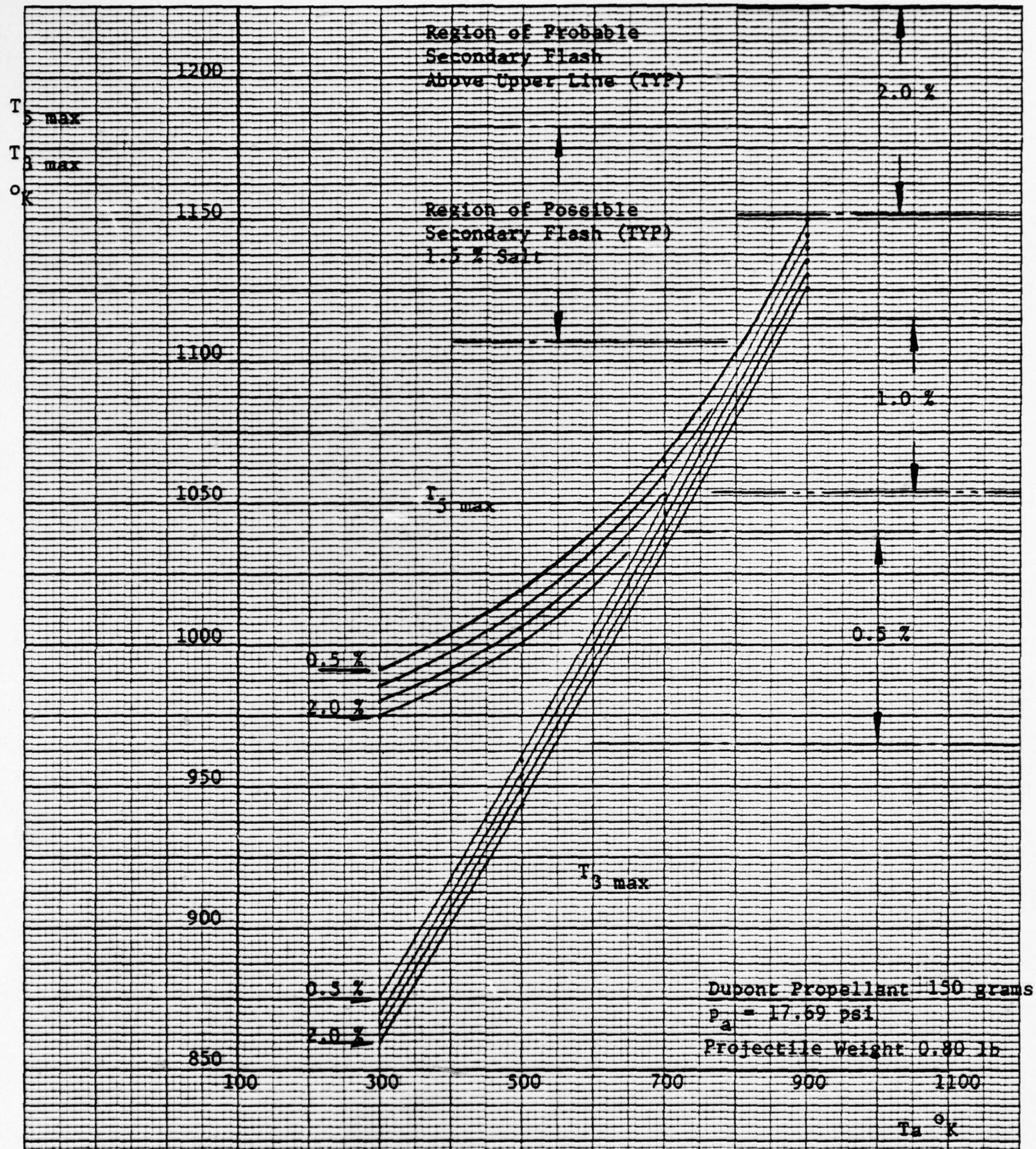


FIGURE 1. COMPUTER PREDICTED MUZZLE GAS TEMPERATURES T_3 AND T_5 FOR VARIATIONS IN AMBIENT AIR TEMPERATURE

shots were fired. This implied that the buildup of temperature may occur during flight and may be the crucial factor in SSBF unless the device is specifically designed to rapidly disperse and mix the gun gas products so that the ambient conditions remain low.

Design of 30-mm Mann Barrel Flash Suppressor

The temperatures T_{3max} are of more importance to the use of a muzzle device to suppress secondary flash and SSBF because this is the lowest temperature that can be achieved if the flow is expanded and mixed with the ambient gas without passing through a temperature raising shock. Therefore, it was imperative that the device be designed so that it affected the buildup in temperature of the ambient air/gas mixture. In the description of Figure 1, the mixing of the gases must pass through T_{3max} as quickly as possible. This has been attempted in the design considerations for the muzzle device.

Figures 2 and 3 illustrate the design of the muzzle device for use on the Mann barrel. This device is similar but not the same in construction and design theory to a device used on aircraft-mounted 0.50 cal. machine guns in the early 1950's.[4] Figure 4 is a print of the drawing used to produce the muzzle device and shows how it relates to a multibarrel fairing for the GAU8/A. The concept for the muzzle device is as follows:

- The gas at the muzzle is expanded into a cylindrical chamber to drop its pressure by about a factor of 2. (The length of this chamber was the first and prime variable to be examined under the experimental portion of the program. The diameter of this chamber was the third level variable, and it was not found necessary to vary this variable.)
- The gas is weakly shocked to turn the flow parallel to the walls, and is then strongly shocked by the intrusion of the seven bars. (The width of the bars was the fourth level variable and it did not require examination.) This intrusion will also cause turbulence in the flow.
- The gas between the bars will be expanded through the action of the cone, along with a turbulent expansion from the central core into the region between the bars.

FIGURE 2. SIDE VIEW OF MUZZLE DEVICE FOR USE ON 30-MM GAU8/A MANN BARREL

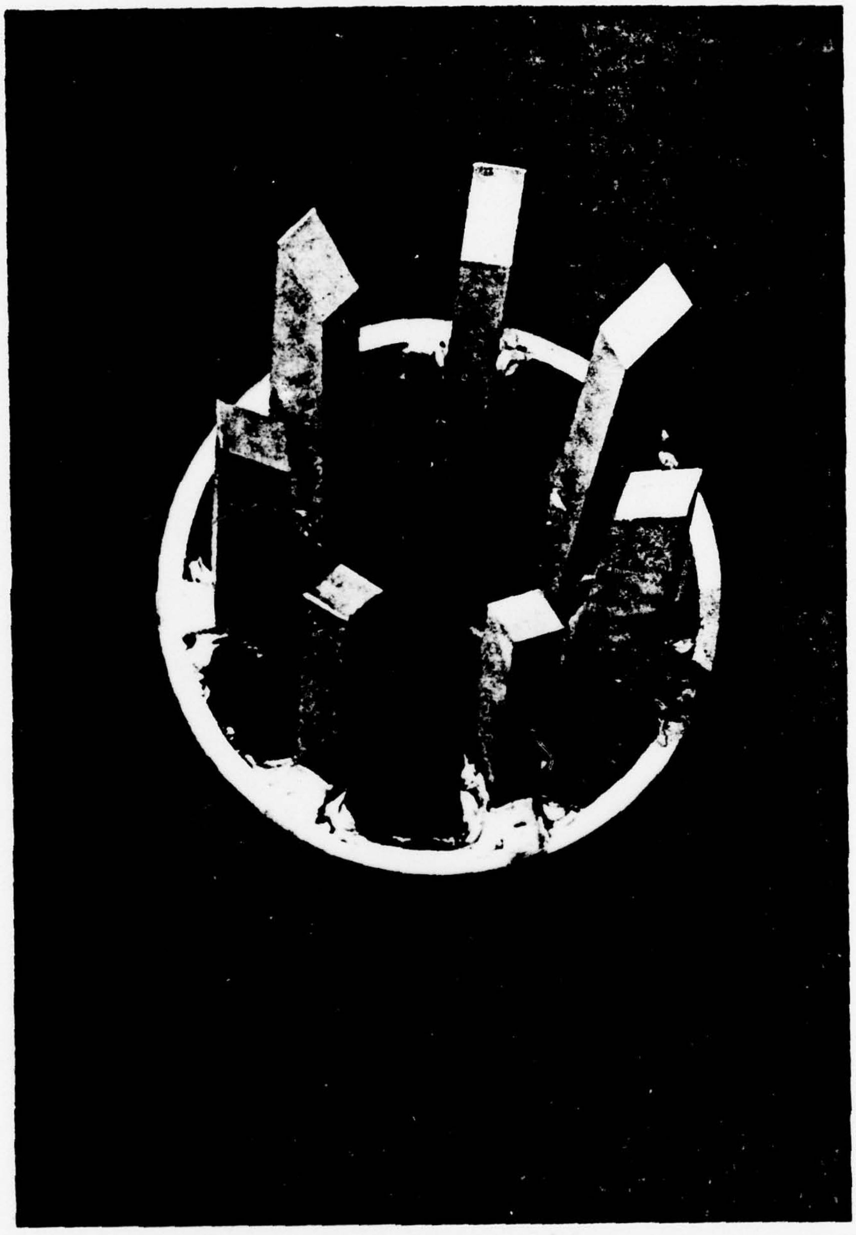
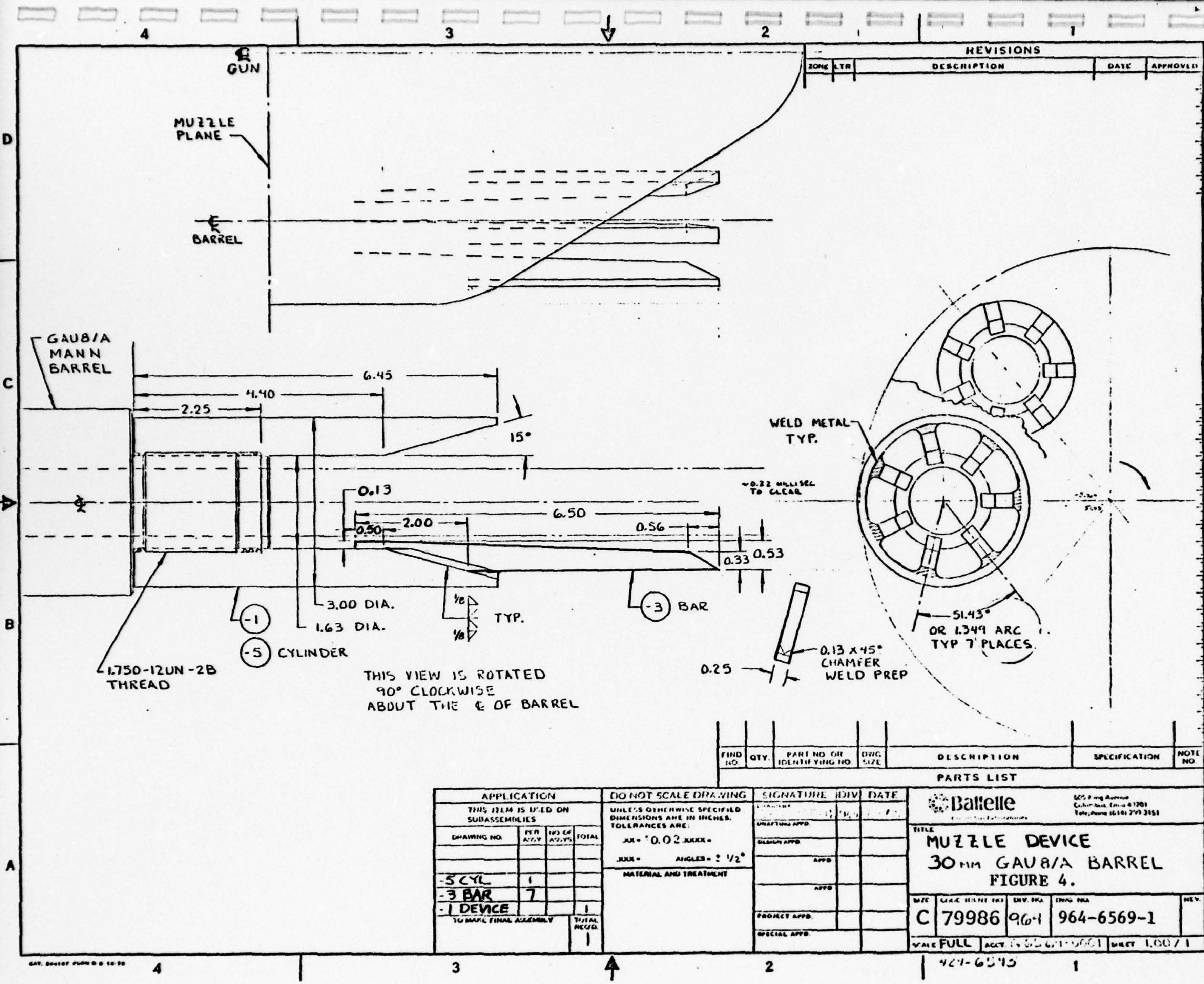


FIGURE 3. END-ON VIEW OF MUZZLE DEVICE FOR USE ON 30-MM GAU8/A MANN BARREL


REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
℄ GUN
MUZZLE PLANE
℄ BARREL
GAU8/A MANN BARREL
6.45
4.40
2.25
15°
0.13
2.00
0.50
6.50
0.56
0.33 0.53
~0.22 MILLISEC TO CLEAR
3.00 DIA.
1.63 DIA.
1/8
1/8
TYP.
-1
-5 CYLINDER
-3 BAR
1.750-12UN-2B THREAD
THIS VIEW IS ROTATED 90° CLOCKWISE ABOUT THE ℄ OF BARREL
WELD METAL TYP.
51.43° OR 1.349 ARC TYP 7 PLACES
0.13 x 45° CHAMFER WELD PREP
0.25
FIND NO. QTY. PART NO OR IDENTIFYING NO DWG SIZE DESCRIPTION SPECIFICATION NOTE NO.
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO. PER ASSY NO OF ASSYS TOTAL
-5 CYL 1
-3 BAR 7
-1 DEVICE 1
TO MAKE FINAL ASSEMBLY
TOTAL REQ'D. 1
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
.XX = ±0.02 .XXXX =
.XXX = ANGLES = ± 1/2°
MATERIAL AND TREATMENT
SIGNATURE DIV DATE
DRAFTING APPD
DESIGN APPD
APPD
APPD
PROJECT APPD.
SPECIAL APPD.
Battelle
TITLE
MUZZLE DEVICE
30 MM GAU8/A BARREL
FIGURE 4.
SIZE C 79986 964 964-6569-1
SCALE FULL
SHEET 1 OF 1
424-6545
DWG. NO.

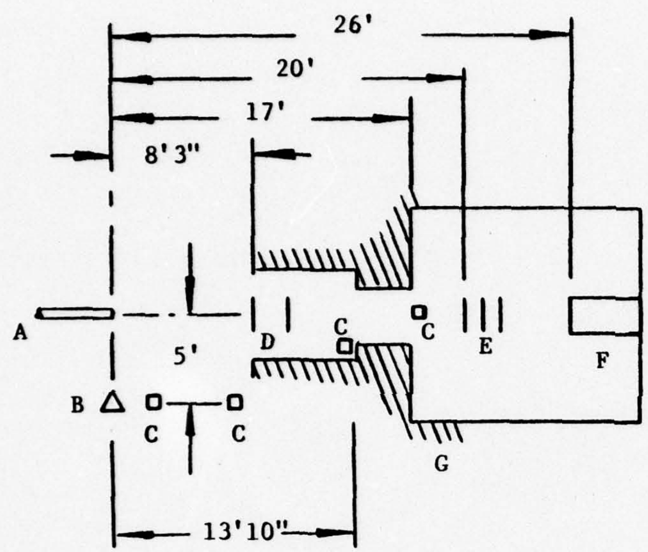
- The flow is expanded out between the bars in a turbulent mode so that it will rapidly mix with the ambient gas. (The length of the bars was the second variable. Due to the negligible effect on the weight of the device and the fact that it had a successful performance, this variable was not examined.)

On the gun system design, the fairing is used to guide the gun gas so that it is mixed to the side as the gun rotates. This is done to slow down the buildup in temperature of the gas/air mixture to the front of the gun, as well as to cool down the escaping gas as quickly as possible so that it won't ignite and SSBF.

Experimental Measurements of Muzzle Flash and Ballistic Data

For the experimental portion of the program during which data was collected for comparison with the computer flash predictions, the 30-mm Mann barrel was set up on the gun stand at Battelle's West Jefferson facility. The instruments for measuring the projectile velocity, radio frequency emissions, and light emissions were assembled. Eight rounds of Honeywell T.P. ammunition (lot no. OL-12-03-76) were initially used to debug and check out the instrumentation. Unfortunately, the ammunition contained 2.0 percent potassium sulfate and could not produce a secondary muzzle flash. The velocity of the projectiles at twenty feet averaged 3437 ft/sec.

Figure 5 depicts the experimental arrangement that was used for both debugging the instrumentation and for recording the data during the program. Figure 6 demonstrates the typical signals generated by the 5-ft monopole antenna and a silicon phototransistor sensor. The circuit for the phototransistor is shown in Figure 7. The silicon phototransistor should have a response time on the order of 10 microseconds. The actual response time is not important so long as it is fairly uniform and is within that ballpark when used with the millisecond sweep speed. The intent was to compare the recorded data and not to make absolute measurements from it. The wave form, vertical displacement with time, was similar in all aspects for the six shots recorded. The first very small spike on the illustrated record may be the precursor flash. The primary muzzle flash



A 30-mm Mann Barrel

B 5-ft Monopole and Selenium Cell Sensors

C Selenium Cell and Silicon Phototransistor Sensors

D Light Change Velocity Screens

E Aluminum Foil Make Circuit Velocity Screens or Cardboard Yaw Cards

F Backstop

G Building Walls

FIGURE 5. MUZZLE FLASH PROGRAM EXPERIMENTAL ARRANGEMENT

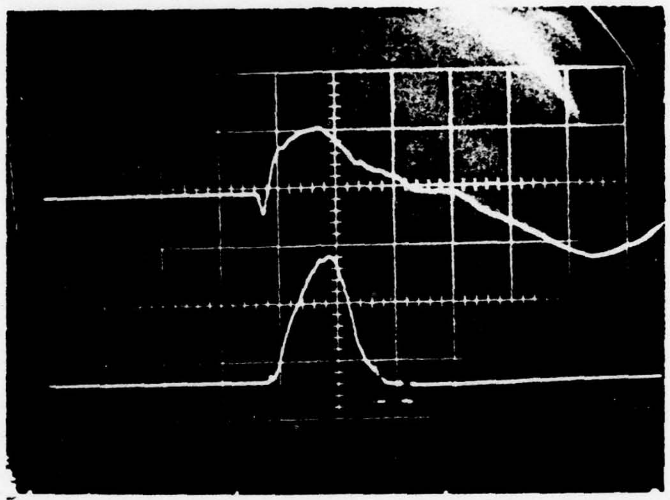


FIGURE 6. MEASUREMENTS OF MUZZLE PHENOMENA OF TP AMMUNITION AS SUPPLIED WITH APPROXIMATELY 2.0 PERCENT SALT CONTENT.

Upper Trace - 5-ft hollow brass tubing monopole antenna connected to 30-ft of RG58 cable directly connected to the Techtronix 555 scope input channel with a 0.5 volt/cm vertical sensitivity.

Lower Trace - Silicon Phototransistor, Radio Shack 276-130, response to primary muzzle flash at a scope sensitivity of 0.5 volt/cm (circuit schematic is in Figure 4).

Sweep Time is 1 msec/cm triggered from gun hammer fall.

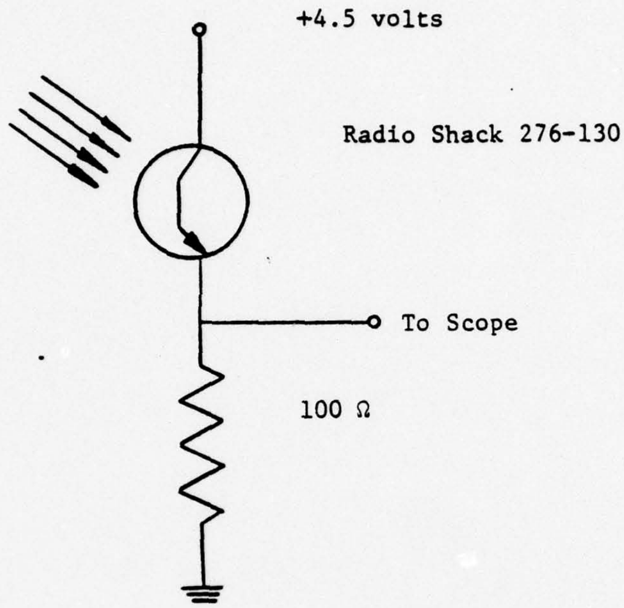


FIGURE 7. SCHEMATIC OF SENSING CIRCUIT FOR THE SILICON PHOTOTRANSISTOR.

is the principal record. The electrical noise at the end of the primary flash can be attributed to the blast wave impacting the power cable and battery which were not secured. Even this noise was similar in all the records.

In addition to the infrared sensitive silicon phototransistor sensors, selenium photoelectric cells were used to measure visible output from the occurrence of the muzzle flashes. A typical cell has a maximum output of 0.5 volts, has a very fast rise time, and somewhat of a memory which was detrimental to absolute measurement of the flashes. Furthermore, typically only about one percent of the emitted light from a muzzle flash is in the visible region. Therefore, the output of the selenium cell and silicon phototransistor sensors located at 17 ft from the muzzle were recorded together on a Tektronix 502 oscilloscope for easy comparison, and some of their recordings were compared to high speed movie documentation at 500 and 5,000 frames per second. From the comparisons conducted during the program, it was determined that the sensors were reliably determining the relative magnitudes and time durations of the muzzle flashes.

During the course of the program, the following three different propellants were used:

- DuPont propellant (8588) containing 0.5 percent K_2SO_4 in grain and 1.5 percent K_2SO_4 pelletized (supplied in the delivered ammunition, 30 mm T.P. Ammunition Lot No. OL-12-03-76)
- Hercules propellant (HC-25-B, Lot 021) containing 0.048 percent KNO_3 in grain
- DuPont propellant (8601) (unsuppressed EX8515).

Table 3 lists the measured muzzle velocities that were used for the initial ballistic comparison of the propellants. Because of the poor ballistic performance of the unsuppressed virgin DuPont propellant, the outside diameter, length, and perforation diameter of randomly selected grains of each of the three propellants were measured. This data is tabulated in Tables 4 and 5.

The performance of the propellants was further examined by using a Kistler model 217C ballistic pressure transducer to monitor the pressure in the barrel at the neck of the cartridge case. Figure 8 illustrates the data taken for three of the comparison firings. It is quite obvious that the DuPont 8601 propellant performed poor ballistically and acted as if it were too heavily deterred.

TABLE 3. BALLISTIC COMPARISONS OF DUPONT (2.0 %), HERCULES (0.5 %), AND DUPONT 8601 (Virgin) PROPELLANTS

	PROPELLANT		
	A	B	C
	Velocity (Ft/Sec) at 20 Ft		
120 Grams (6)	2816	2809	2298
	2808	2841	2463
	2812	2841	2632
	2866	2907	
		2817	
		2882	
135 Grams (6)	3096	3135	2722
	3125	3135	2755
	3135	3174	2828
150 Grams		3473	3118
		3485	3100
		3426	3133
		3437	
T.P.	3425		
as Delivered	3425		
(154 Grams)	3460	--	--

NOTES:

(1) Propellant A is the DuPont propellant containing 0.5 % K_2SO_4 in grain and 1.5 % K_2SO_4 pelletized.

(2) Propellant B is the Hercules propellant containing 0.5 % KNO_3 in grain.

(3) Propellant C is the DuPont 8601 (unsuppressed EX8515) propellant.

(4) T.P. projectile weights averaged 364 grams.

(5) Velocity recorded by light screens and/or close contact aluminum foil screens.

(6) A small amount of cotton wadding was placed on top of the charge to promote consistent propellant bed ignition.

TABLE 4. EXTERIOR DIMENSIONS OF PROPELLANT GRAINS

	Propellant A		Propellant B		Propellant C	
	Length	Outside Diameter	Length	Outside Diameter	Length	Outside Diameter
	0.093	0.073	0.088	0.066	0.087	0.067
	0.090	0.072	0.086	0.065	0.091	0.066
	0.092	0.075	0.092	0.065	0.095	0.065
	0.093	0.074	0.088	0.066	0.087	0.067
	0.090	0.076	0.089	0.066	0.087	0.066
	0.090	0.073	0.087	0.068	0.095	0.068
	0.091	0.072	0.089	0.068	0.089	0.064
	0.093	0.076	0.086	0.067	0.087	0.067
	0.086	0.074	0.088	0.065	0.087	0.064
	0.091	0.077	0.087	0.066	0.087	0.066
Average	0.091	0.074	0.088	0.066	0.089	0.066

NOTES:
(1) Propellant A is the DuPont propellant containing 0.5 % K_2SO_4 in grain and 1.5 % K_2SO_4 pelletized.
(2) Propellant B is the Hercules propellant containing 0.5 % KNO_3 in grain.
(3) Propellant C is the DuPont 8601 (unsuppressed EX8515) propellant.
(4) All dimensions in inches.

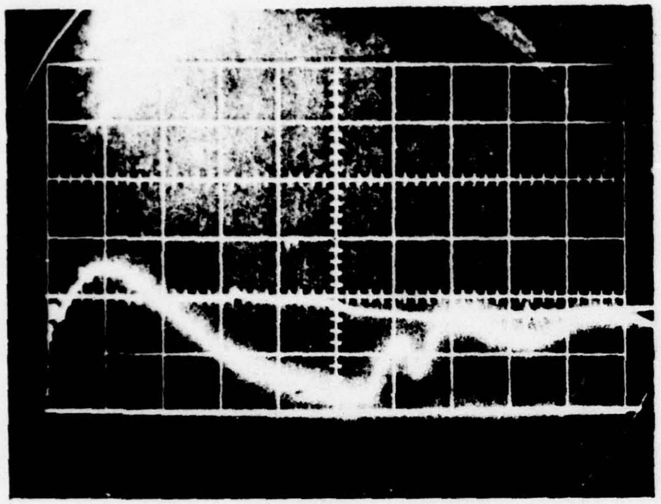
TABLE 5. PROPELLANT GRAIN PERFORATION DIAMETERS

	Propellant A	Propellant B	Propellant C
	0.0065	0.0085	0.0060
	0.0060	0.0065	0.0065
	0.0055	0.0060	0.0070
	0.0075	0.0065	0.0060
	0.0090	0.0058	0.0068
	0.0078	0.0050	0.0068
	0.0085	0.0051	0.0078
	0.0060	0.0061	0.0055
	0.0085	0.0065	0.0050
	0.0070	0.0065	0.0060
AVERAGE	0.0072	0.0063	0.0063

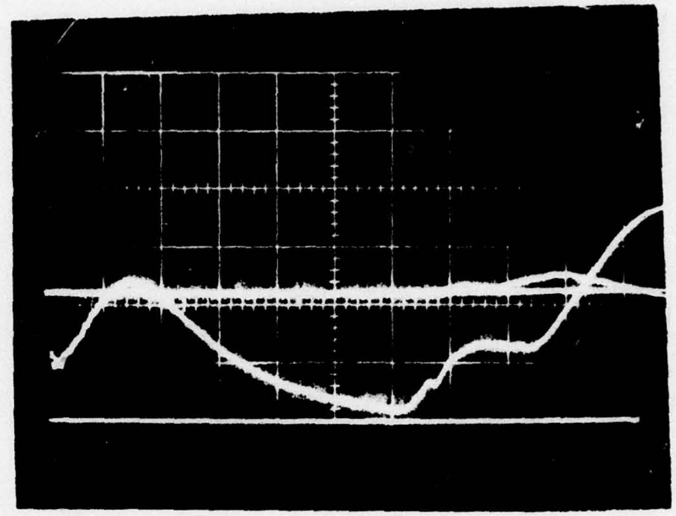
NOTES: (1) Propellant A is the DuPont propellant containing 0.5 percent K_2SO_4 in grain and 1.5 percent K_2SO_4 pelletized. It is supplied in the TP ammunition.

(2) Propellant B is the Hercules propellant containing 0.5 percent KNO_3.

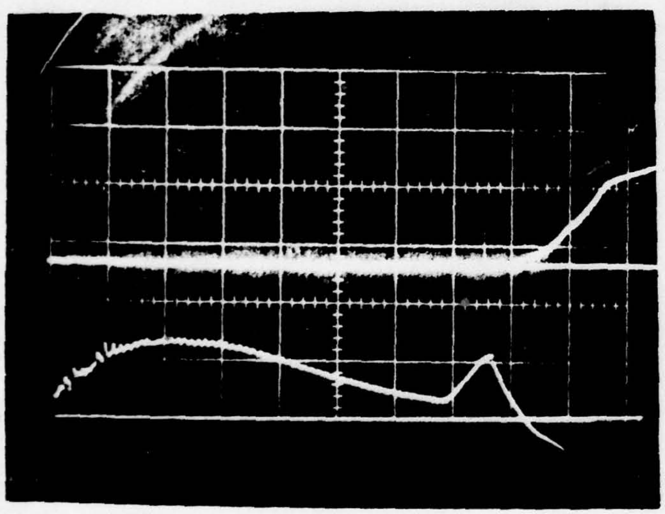
(3) Propellant C is the DuPont 8601 (unsuppressed EX8515) propellant.



Record A - T.P. Round (3421 ft/sec)



Record B - 150 grams Hercules Powder (3480 ft/sec)



Record C - 150 grams DuPont 8601 + 11.6 grains K_2SO_4 (3170 ft/sec)

Upper Trace - silicon phototransistor at 6 ft from muzzle, vertical sensitivity 0.5 v/div
sweep speed - 1.0 msec/div - record A
- 0.5 msec/div - records B,C

Lower Trace - A - Kistler 217C ballistic pressure transducer (0.047 mv/psi) 1.0 v/div;
B - 5 ft antenna record inverted and added at 0.2 v/div
sweep speed - 0.5 msec/div - records A, B, C

NOTE: scope trigger is from pressure record

FIGURE 8. INTERIOR BALLISTIC CYCLE PERFORMANCE OF THE AS-RECEIVED T.P. AMMUNITION AND THE RELOADED AMMUNITION WITH T.P. PROJECTILES

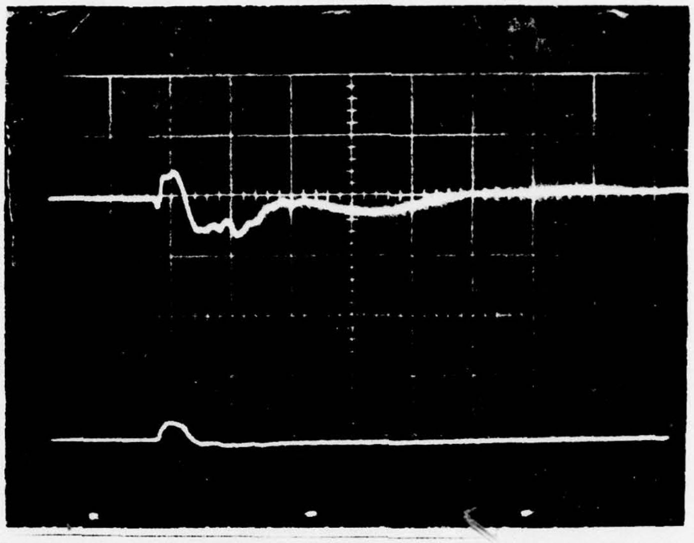
Due to the short time available for the program and the need to use a propellant with no incorporated suppressant salts, it was decided to use the 8601 propellant. Although it yielded muzzle velocities that were too low, it did produce a significant secondary muzzle flash. The use of the propellant then was considered to be an overtest on the effectiveness of the design of the muzzle device to suppress secondary muzzle flash.

Figures 9 through 14 illustrate the occurrence of primary and secondary muzzle flash for the Hercules and DuPont 8601 propellants. In Figure 9, the 0.48 percent of KNO_3 suppressant salt incorporated in the propellant grains is observed to be sufficient to suppress the secondary muzzle flash without using the muzzle device. When the muzzle device was used, the primary flash as well as the secondary flash was suppressed. This suppression of the primary flash can either be considered as a hiding of this flash by the device if the gun barrel muzzle is used as the reference plane or as a suppression if the exit plane of the device is used as the reference plane.

Figures 10, 11, and 12 illustrate the occurrence of secondary flash when the projectile weight is decreased. It can be observed that the measured magnitude (although not calibrated) of the primary flash increases with decreasing projectile weight. The time duration of the secondary flash is also noted to increase with decreasing projectile weight. Furthermore, it is noted that the muzzle device not only suppresses the secondary flash but also the primary flash which still increases in magnitude with decreasing projectile weight in the suppressed case in the same way as in the unsuppressed case.

Figure 13 shows the severity of the flash problem with the unsuppressed DuPont 8601 propellant. Without any suppressant salt, the muzzle device failed to suppress the secondary flash. However, with 0.5 percent of K_2SO_4 suppressant salt added, the muzzle device was capable of suppressing the secondary flash and limiting the magnitude of the primary flash as shown in Figure 14.

Figure 15 further demonstrates the ability of K_2SO_4 to suppress the muzzle flash in conjunction with the mechanical muzzle device. Both the



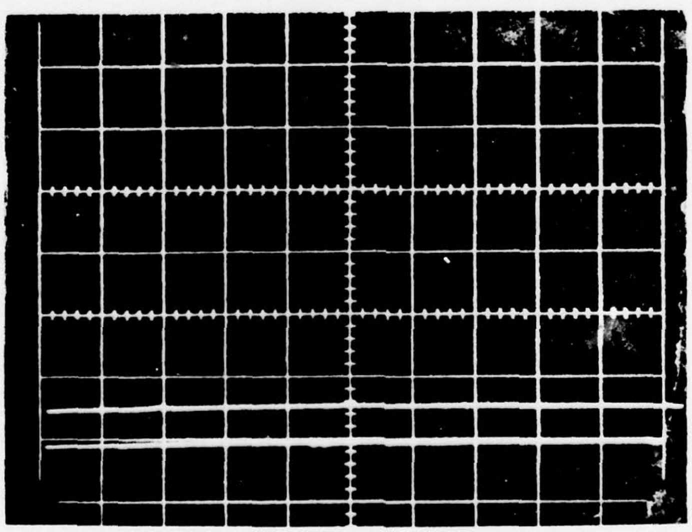
Without Muzzle Device

Record A. Sensor location is 3 ft 6 in. along trajectory, 4 ft 6 in. perpendicular to trajectory, and looking directly at the muzzle

Upper Channel - 5-ft monopole vertical sensitivity 0.5 v/cm

Lower Channel - phototransistor sensor of 2nd progress report, vertical sensitivity 0.5 v/cm

Sweep Speed - 5 milliseconds/centimeter



With Muzzle Device

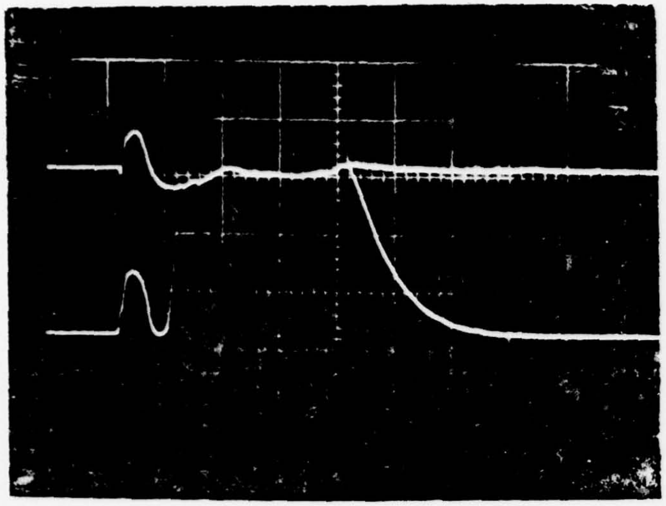
Record B. Location at 17 ft along trajectory, approximately 3 ft above trajectory

Upper Channel - phototransistor same as type used for Record A, vertical sensitivity 0.5 v/cm

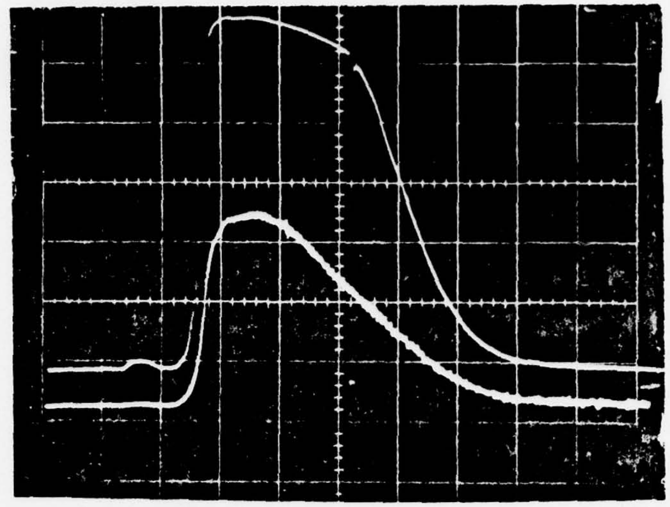
Lower Channel - selenium photocells (3), vertical sensitivity 0.1 v/cm

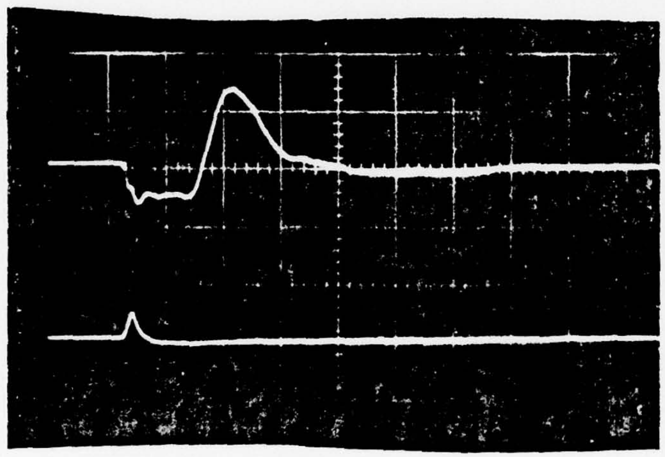
Sweep Speed - 5 milliseconds/centimeter

FIGURE 9. MUZZLE FLASH RECORDS FOR 150 GRAMS OF HERCULES PROPELLANT AND THE T.P. PROJECTILE.



A

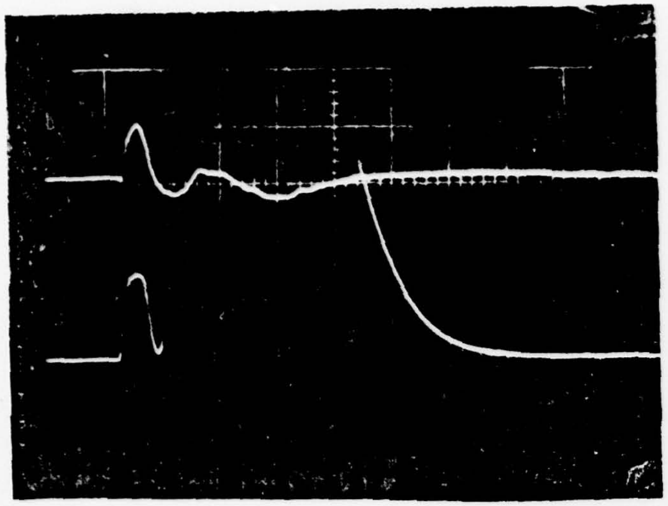




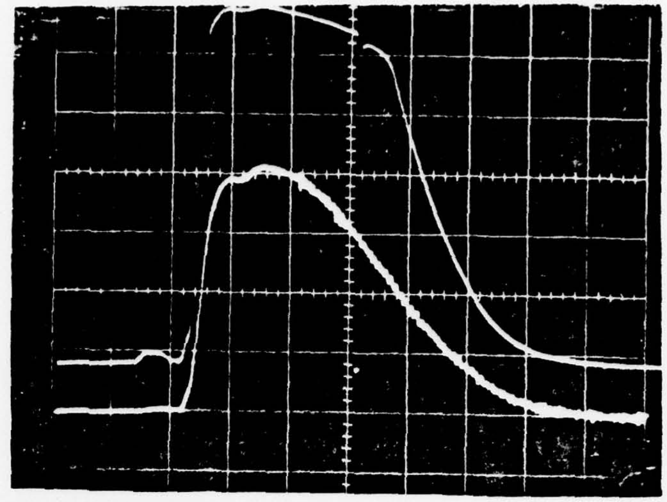
C

FIGURE 11. MUZZLE FLASH RECORDS FOR 150 GRAMS OF HERCULES PROPELLANT AND 0.64-LB PROJECTILE

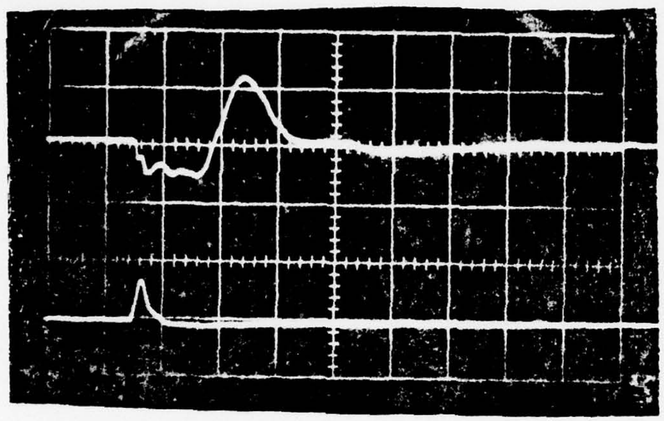
Records A,B same sensors and sensitivity as Figure 9; Muzzle Device not used on gun
Record C same sensors and sensitivity as A; Muzzle Device used to suppress secondary flash



A



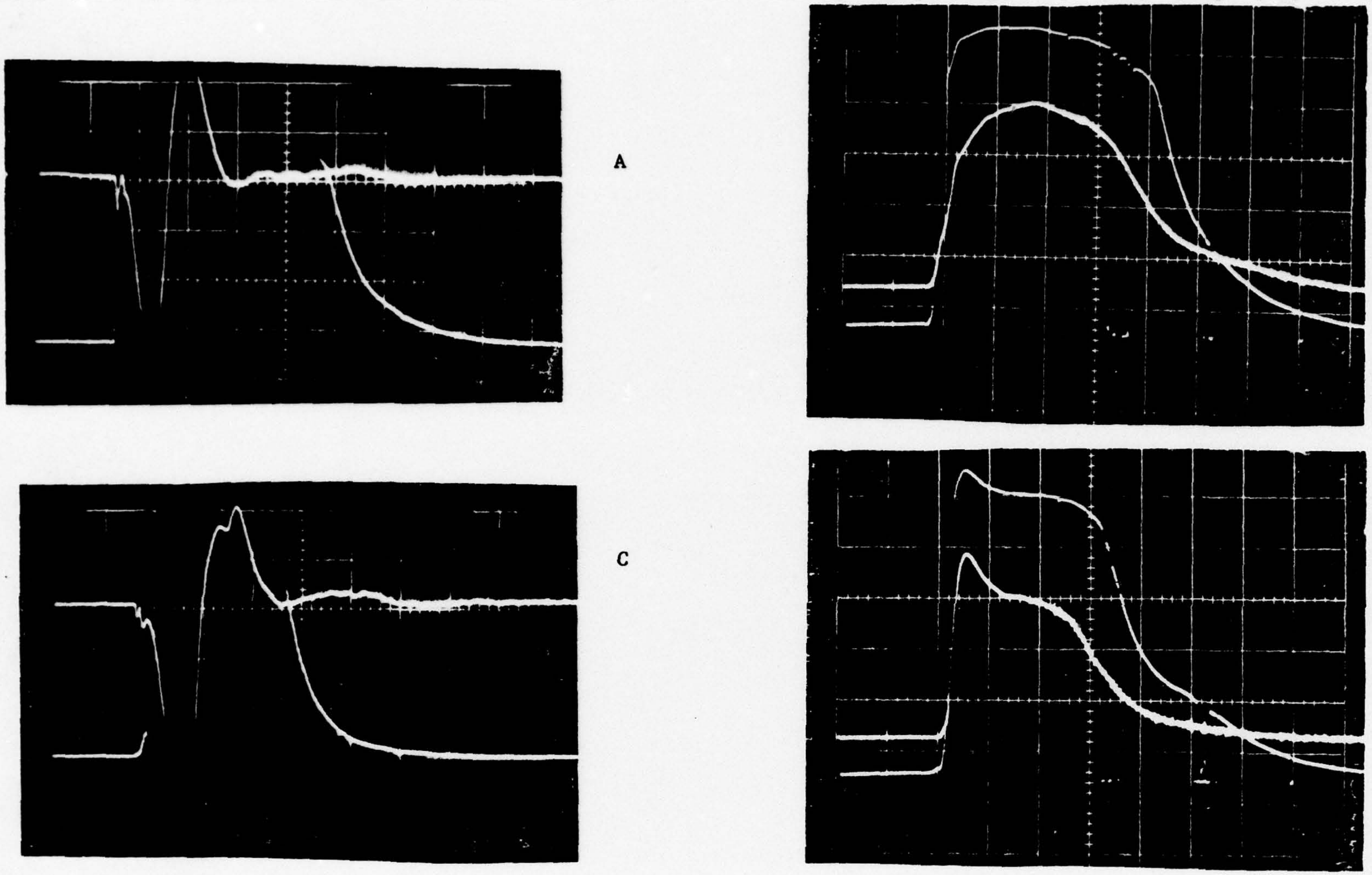
B



C

FIGURE 12. MUZZLE FLASH RECORDS FOR 150 GRAMS OF HERCULES PROPELLANT AND 0.55-LB PROJECTILE

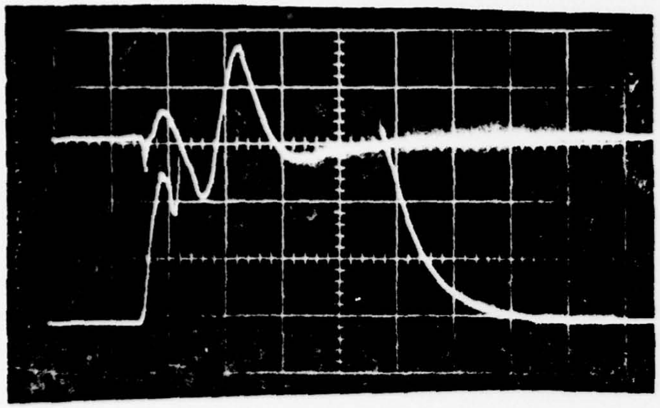
Records A, B same sensors and sensitivity as Figure 9, Muzzle Device not used on gun
Record C same sensors and sensitivity as A, Muzzle Device used to suppress secondary flash



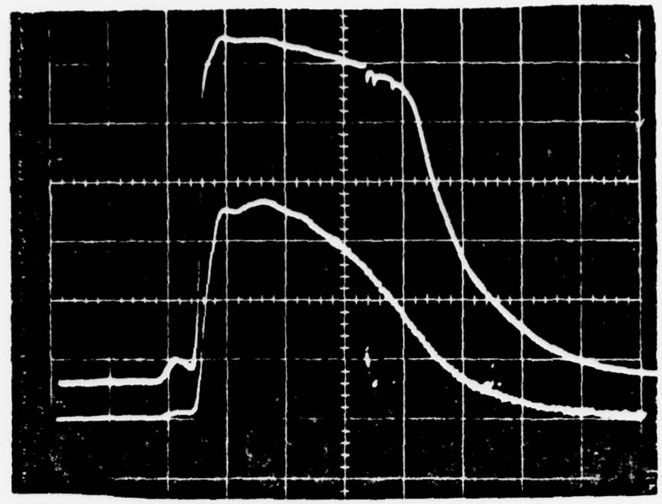
A B C D

FIGURE 13. MUZZLE FLASH RECORDS FOR 150 GRAMS OF DUPONT 8601 (VIRGIN) PROPELLANT AND T.P. PROJECTILE

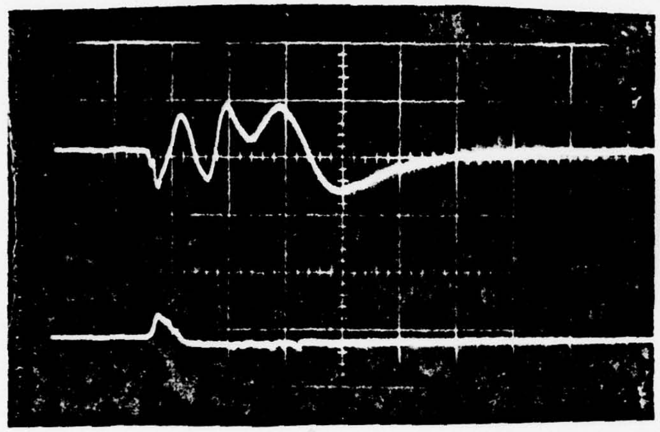
Records A, B same sensor and sensitivity as Figure 9 , Muzzle Device not used on gun
Records C, D same sensor and sensitivity as A, B; Muzzle Device used but flash not suppressed



A



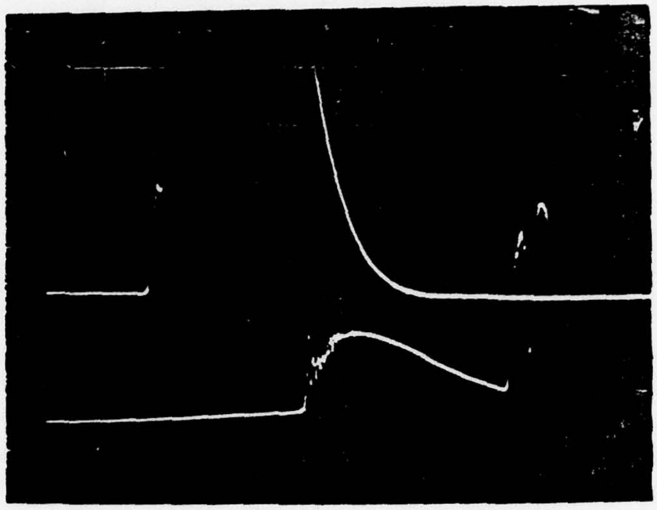
B



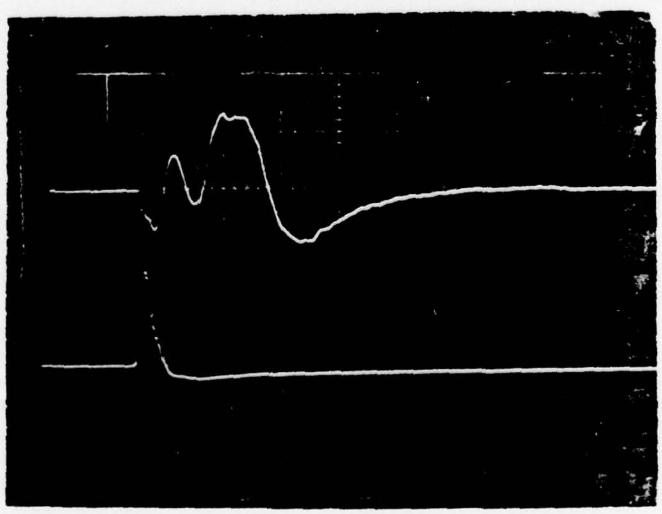
C

FIGURE 14. MUZZLE FLASH RECORDS FOR 150 GRAMS OF DUPONT 8601 (VIRGIN) PROPELLANT WITH 0.5 % OF K_2SO_4 SALT AND T.P. PROJECTILE.

Records A, B same sensors and sensitivity as Figure 9, Muzzle Device not used on gun
Record C same sensors and sensitivity as A; Muzzle Device used to suppress secondary flash



RECORD A - 0.5 percent K_2SO_4, thoroughly mixed with propellant. Sensor location is 3 ft 6 in. along trajectory, 4 ft 6 in. perpendicular to trajectory and looking directly at the muzzle
UPPER TRACE - phototransistor, 0.5 v/div, 5 msec/div
LOWER TRACE - pressure transducer, 1.0 v/div, 5 ft monopole, -0.1 v/div, 1 msec/div



RECORD B - 0.75 percent K_2SO_4 stirred into the top of the charge. Same sensor location as RECORD A.
UPPER TRACE - 5 ft monopole, 0.5 v/div, 5 msec/div
LOWER TRACE - phototransistor, 0.5 v/div, 5 msec/div

FIGURE 15. MUZZLE FLASH RECORDS FOR 150 GRAMS OF DUPONT 8601 PROPELLANT AND A 0.64 LB PROJECTILE

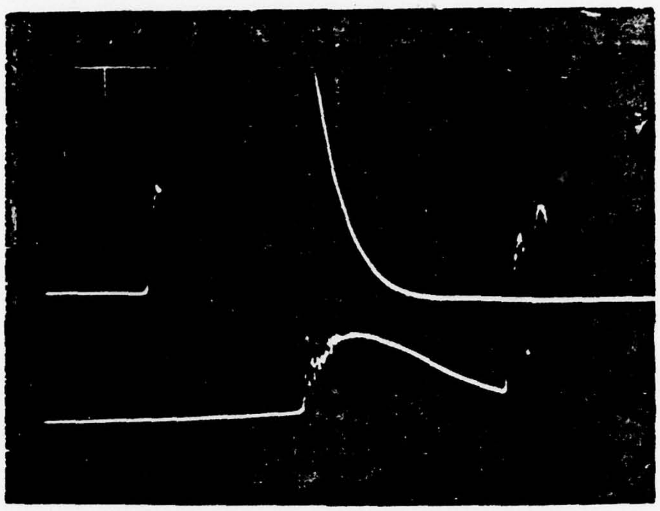
magnitude of the primary muzzle flash and the occurrence of the secondary muzzle flash for a round using a lightweight (0.64 lb) projectile was suppressed by an increment of 5.76 grains of K_2SO_4.

Figure 16 shows the effect of extending the length of the first chamber in the muzzle device by screwing it 0.5 inches off the barrel. The suppression effect is very similar to that achieved by the addition of the salt in Figure 15. The changing of the length of this chamber was considered to be the first variable that would be changed if the muzzle device was unsuccessful in suppressing the secondary flash. However, the as-designed device was successful enough that very little work was required changing this variable.

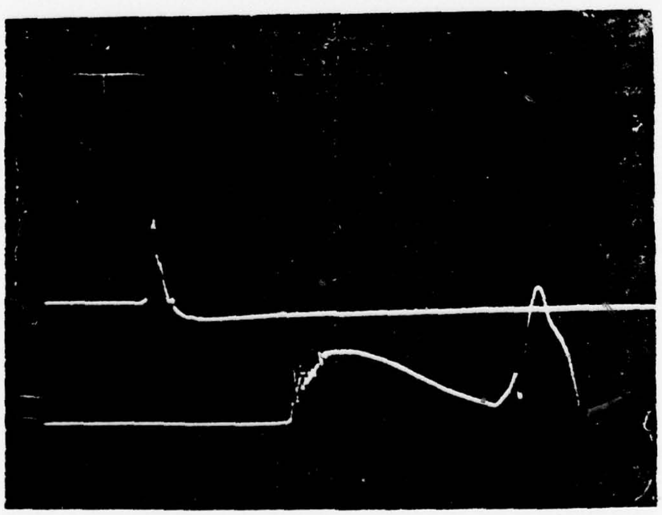
Figure 17 illustrates the difference in suppression achieved by thoroughly mixing the salt with the propellant in contrast to only stirring it into the top of the propellant charge. A number of these comparisons were performed, because Mr. Wayne Hathaway of G.E. and Capt. Bob Powers of AFATL, noticed that there was a significant improvement in the suppressant capability of the salts if they were stirred throughout the entire charge. The experiments performed at Battelle further demonstrated this to be true. Throughout the major portion of this program the suppressant salt was thoroughly mixed with the propellant charge.

Much useful information has been generated by the experimental probing of the propellants, projectile weights, and muzzle device. For example, from Figure 10 where the 0.70-lb projectile was used with the Hercules propellant, the secondary muzzle flash is seen to begin at about 4 milliseconds (msec) after projectile exit. The flash is well developed at 5.5 msec and is quenching from 19 msec to 30 msec. For the aircraft cannon with a firing rate of 4000 spm, a projectile is exiting every 15 msec. This means that there is an overlap time during which the previous secondary flash would ignite the gases from the next shot or the next shot ignite the hot mixing gases from the previous shot and thus, lead to secondary sustained burning and flashing (SSBF).

The study of the effectiveness of the muzzle device was aided by photographing the muzzle flashes of some experiments, both without and with the device, at framing rates of 42, 128, 500, and 5,000 frames-per-second. In the films wherein the device was not used, the development of the primary

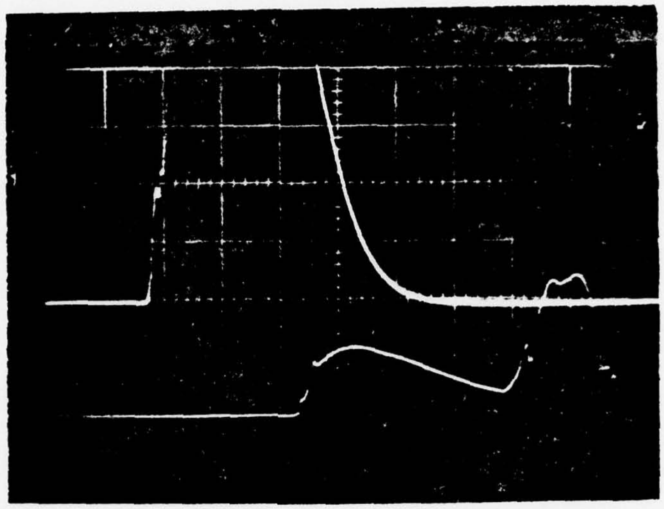


RECORD A - Muzzle device screwed all the way onto barrel. Same sensors and sensitivities as RECORD A of Figure 15.

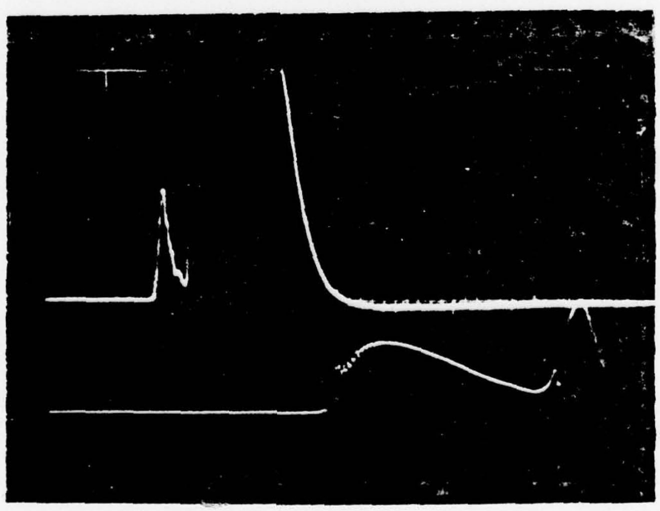


RECORD B - Muzzle device extended 0.5 in. Same sensors and sensitivities as RECORD A of Figure 15.

FIGURE 16. MUZZLE FLASH RECORDS FOR 150 GRAMS OF DUPONT 8601 PROPELLANT WITH 11.6 GRAINS OF K_2SO_4, THOROUGHLY MIXED, AND A 0.64 LB PROJECTILE



RECORD A - K_2SO_4 was stirred into the top of the propellant charge. Same sensors and sensitivity as RECORD A of Figure 15.



RECORD B - K_2SO_4 was distributed throughout the propellant charge by rolling them around in a glass beaker. Same sensors and sensitivity as RECORD A of Figure 15.

FIGURE 17. MUZZLE FLASH RECORDS FOR 150 GRAMS OF DUPONT 8601 PROPELLANT WITH 11.6 GRAINS OF K_2SO_4 AND A 0.64 LB PROJECTILE AND THE MUZZLE DEVICE

and secondary muzzle flash can be followed sequentially. When the device is used, the suppression of the primary and secondary flashes as well as the turbulence of the emptying gases can be observed. In those cases where the muzzle device was unsuccessful, the local ignition of the secondary flash can be seen. From the information on these films, it may be possible that the rotation of the barrel such as will occur on the seven-barrel cannon may provide the turbulence required for the complete suppression even in the cases where the single shot experiment was not successful.

The electromagnetic signals detected by the 5-ft monopole can be observed to vary from configuration to configuration by looking at record A in Figures 9 through 14. This variation is not well understood but may contain important information on the ion flow from the muzzle. Therefore, this information may be invaluable in the future as a design aid in configuring the chemical salt suppressants. It should be noted that these wave forms did not change for repetitions of the same propellant, salt and projectile configurations.

It is especially noted from Figures 9 through 14 that the muzzle device not only suppresses the secondary muzzle flash, but it also significantly affects the primary muzzle flash and the signal monitored by the 5-ft monopole. This is true in all cases observed to date, including that where the secondary flash from the 8601 propellant was not suppressed.

Tables 6 and 7 present a summary of the experiments both with and without the muzzle device for ammunition reloaded with the Hercules and DuPont propellants, respectively. These tables summarize the flash data in a form from which the performance of the muzzle device and chemical suppressant salts can be observed. Each of the symbols represents from one to four experiments. Other experiments were performed that are not tabulated because they do not impact the significance of the performance of the muzzle device. The experiments using the Hercules propellant with additional concentrations of suppressant salt fall in this category because the device always suppressed the flash for these experiments. Table 6 represents the worst cases wherein no additional salt was added to this propellant. It can be seen that in the cases presented that the device was still always successful in suppressing the secondary flash.

TABLE 6. OBSERVATIONS OF SECONDARY FLASH FROM AMMUNITION RELOADED WITH HERCULES PROPELLANT (HC-25-B)

Charge Weight (grams)	Projectile Weight (lb)					
	0.55	0.60	0.64	0.70	0.74	0.80
150	F/S	F/S	F/S	F/S	F, NF/S	NF
145						NF/S*
140						NF/S*
135	F/S	F/S	NF/S*	F/S	NF/S*	NF/S*
120						NF, F/S*

<u>CODE KEY</u>

F - secondary flash was observed without device
NF - secondary flash was not observed without device
S - device suppressed secondary flash
S* - device significantly reduced primary flash, no secondary flash was observed
NS - device did not suppress secondary flash

TABLE 7. OBSERVATIONS OF SECONDARY FLASH FROM AMMUNITION RELOADED WITH 150 GRAMS OF DUPONT PROPELLANT (8601)

Weight (percent) of K_2SO_4 Suppressant Salt (grains)	Projectile Weight (lb)					
	0.55	0.60	0.64	0.70	0.74	0.80
0 (0 %)						F/NS**, NS***
11.60 (1/2 %)	F/NS, NS*, S**, NS**, S***, NS***	F/S*, NS*, S**	F/NS, NS*, S**	F/NS, NS*, NS**, NS***	F/NS, S*, NS*, S**	F/S
17.36 (3/4 %)	F/NS, S*, NS*,	F/S*, NS*, S**	F/S	F/S		F/S
23.15 (1 %)	F/S		F/S	F/S		F/S
34.72 (1-1/2 %)	F/S		F/S	F/S		F/S

CODE KEY

F - secondary flash was observed without device
S - device suppressed secondary flash
NS - device did not suppress secondary flash
* - potassium sulphate and propellant were mixed by rolling them around in a glass beaker. Symbols without asterisk(s) represent firings where the salt was stirred into the top of the propellant charge.
** - 0.5 inches was added to the device's chamber length by turning it off the threaded muzzle.
*** - 1.0 inch was added to the device's chamber length by turning it off the threaded muzzle.

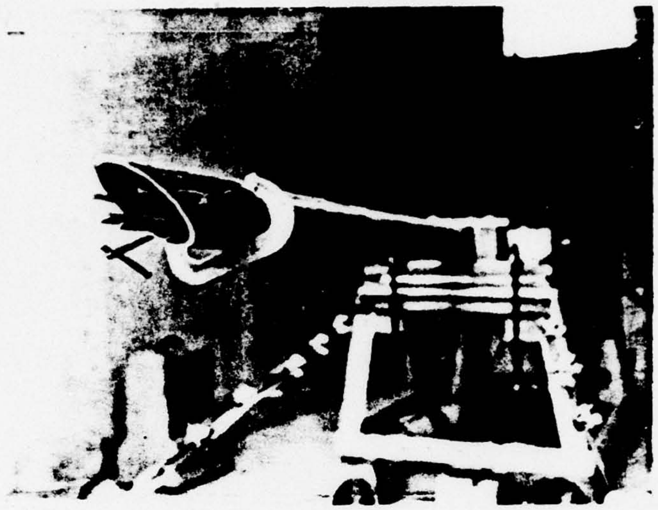
Table 7 summarizes the effect of the different levels of salt suppressant, the effect of fully mixing it through the charge versus stirring it only into the top, and the adjustment of the length of the cylindrical portion of the device.

Figure 18 shows the two cylinders that were slipped over the outside of the muzzle device in order to study how the performance of the device might be adversely affected by its incorporation in a seven barrel faired configuration. Both the Hercules propellant and the DuPont 8601 propellant with 11.6 grains K_2SO_4 suppressant salt were used with projectile weights of 0.8, 0.74, 0.7, 0.64, 0.6, and 0.55 pounds to study the effect of the cut cylinders. The results of some of these evaluations are presented in Figures 19, 20, and 21.

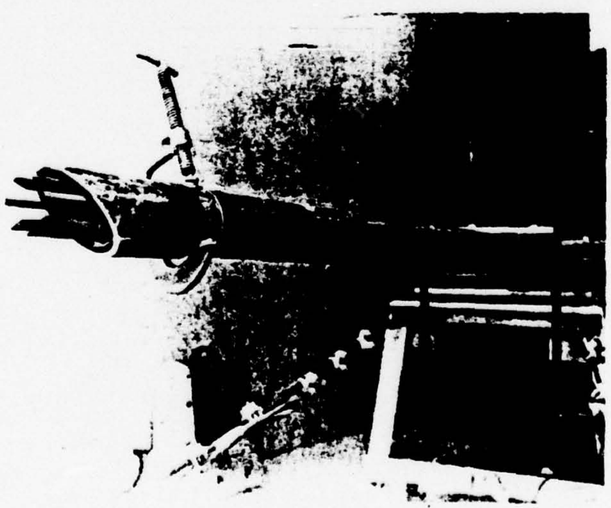
In Figures 19 and 20, depicting the 30 degree and 45 degree cylinder results respectively, ignition and burning irregularities caused by the 0.55 lb projectile can be noticed. In both these figures, some secondary flash is observed with the Hercules propellant. It is not known at present how the ignition irregularities may have affected the formation of the flashing of the Hercules propellant. However, both these cases were very severe overtests of the device. They can be disregarded for design purposes as being well beyond the expected gun system performance, but they do document the device's limit.

Figure 21 illustrates the smoother ballistic cycle obtained when the projectile weight was 0.60 lb, as well as the effectiveness of the muzzle device with the 45 degree cut cylinder in eliminating the secondary muzzle flash. In the records in this figure, only the primary flash is observed.

As a result of the experimental efforts using the cut cylinders, a 45 degree fairing between the muzzle exits of the seven barrels appears to be the best solution for the combination of flash suppression effectiveness, seven-barrel device weight, and reduction of undesirable side thrust on the gun system. Thus, the design of the seven-barrel device, that will probably weigh less than 65 lb, should incorporate a 45 degree center fairing, the fingers of the single shot device, and the chamber length of the single shot device.

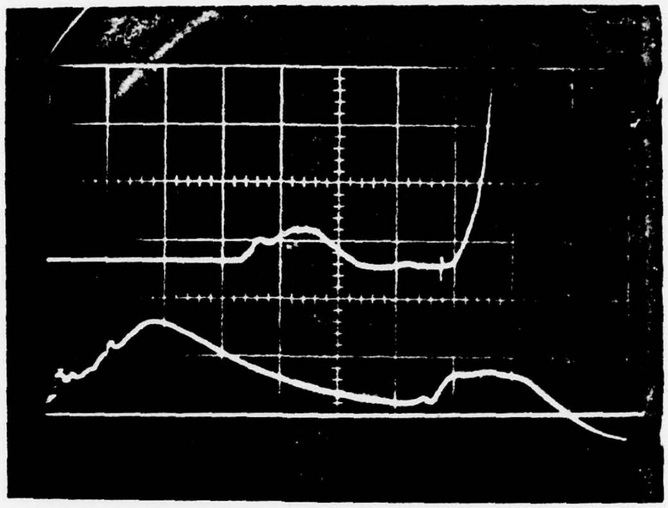


Record A - 30 Degree Cylindrical Fairing Over the Muzzle Device

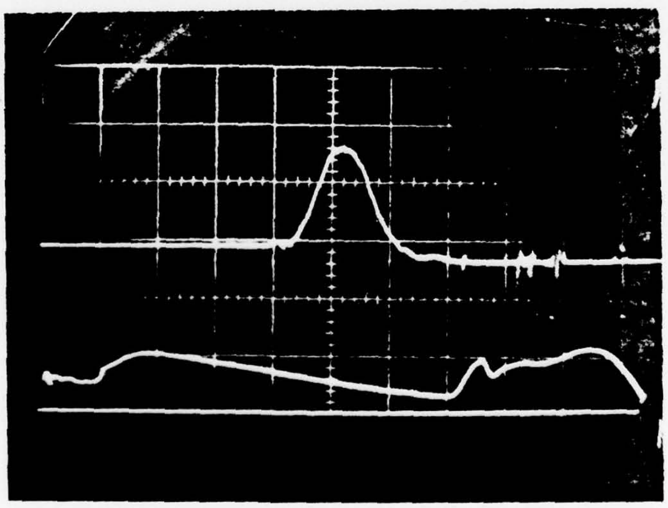


Record B - 45 Degree Cylindrical Fairing Over the Muzzle Device

FIGURE 18. PHOTOGRAPHS OF THE MODIFICATIONS TO THE MUZZLE DEVICE IN ORDER TO STUDY ITS ADAPTABILITY INTO A SEVEN BARREL CONFIGURATION



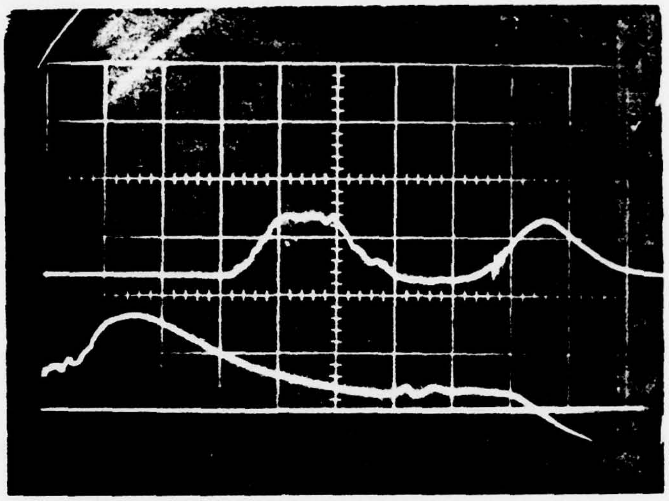
Record A - 150 grams Hercules Propellant (3776 ft/sec)



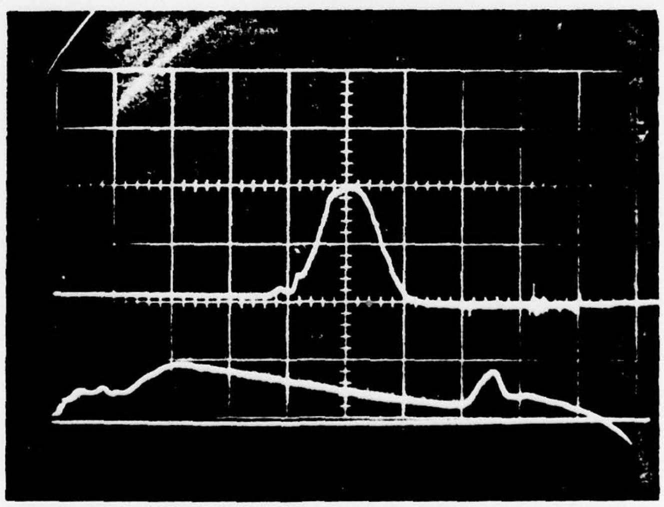
Record B - 150 grams DuPont 8601 Propellant with 11.6 grains K_2SO_4 (3279 ft/sec)

NOTE: Oscilloscope parameters are the same as Figure 18A

FIGURE 19. MUZZLE FLASH AND PRESSURE/TIME RECORDS FOR AMMUNITION USING 0.55 LB PROJECTILES AND THE MUZZLE DEVICE WITH THE 30 DEGREE CUT CYLINDER



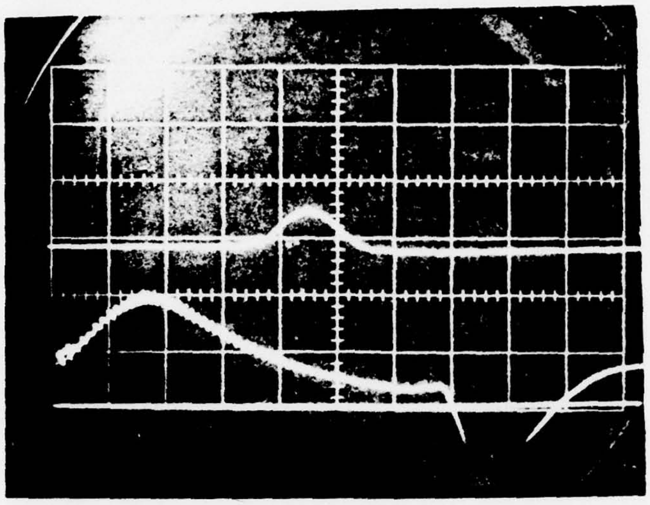
Record A - 150 grams Hercules Propellant (3665 ft/sec)



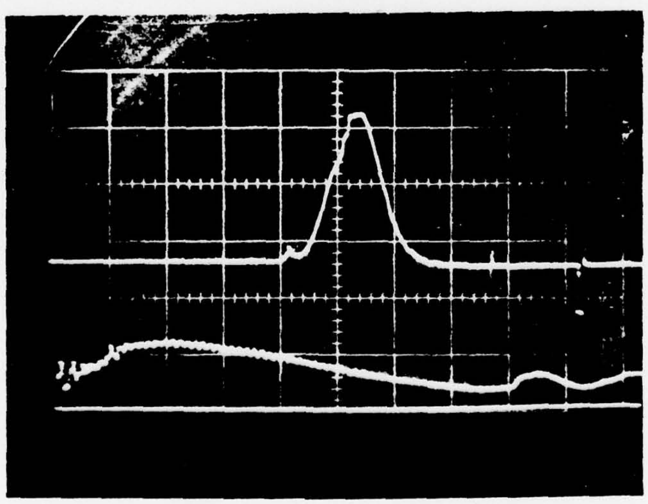
Record B - 150 grams DuPont 8601 Propellant with 11.6 grains K_2SO_4 (3377 ft/sec)

NOTE: Oscilloscope parameters are the same as Figure 18A

FIGURE 20. MUZZLE FLASH AND PRESSURE/TIME RECORDS FOR AMMUNITION USING 0.55 LB PROJECTILES AND THE MUZZLE DEVICE WITH THE 45 DEGREE CUT CYLINDER



Record A - 150 grams Hercules Propellant (3645 ft/sec)



Record B - 150 grams DuPont 8601 Propellant with 11.6 grains K_2SO_4 (3260 ft/sec)

NOTE: Oscilloscope parameters are the same as Figure 18A

FIGURE 21. MUZZLE FLASH AND PRESSURE/TIME RECORDS FOR AMMUNITION USING 0.6 LB PROJECTILES AND THE MUZZLE DEVICE WITH THE 45 DEGREE CUT CYLINDER

Table 8 summarizes the experiments conducted to investigate the effect of the fairing. It is noted that the combination of the device and the two fairings(30 degree and 45 degree cut cylinders) only failed to suppress the secondary flash for the 0.55 lb projectile weight. And these experiments represented a severe overtest.

Comparisons Between Recorded Data And Computer Predictions

In order to verify the computer model as a reasonable means by which to extrapolate the ground testing into flight conditions, the ballistic performance of the reloaded ammunition was matched for pressure/time projectile exit time, and muzzle velocity. Once this was achieved broadly for a number of projectile weights and/or propellant loadings, then the muzzle velocity and flash information was generated for all the cases that were examined experimentally.

Figure 22 illustrates the match between the recorded pressure in the barrel at the neck of the cartridge and computed chamber pressure. The difference between the two curves is an approximation to the fact that the ballistic gage records the static pressure and that this pressure is different from that in the chamber because the gas has considerable dynamic pressure when the projectile is moving at a high velocity.

Table 9 permits the comparison of the measured muzzle velocities of those experiments that were successfully measured and the computer predicted velocities that utilized the deterred burning geometry that made the match shown in Figure 22. The most significant dispersion in measured velocities occurs in the case where the full propellant load of 150 grams is used with the 0.55 lb projectile. In these cases, it has been previously shown in Figures 19 and 20 that the pressure/time record was irregular. This irregularity may be the cause for the 157 ft/sec (4 percent) spread between the measured velocities. However, the grouping of the velocities is still nicely distributed about the predicted velocity and averages 3759 ft/sec.

Figure 23 illustrates the T_3 and T_5 temperatures predicted for the 150 grams of Hercules propellant loadings listed in the top of Table 9. The computer output shows a discontinuity in the predicted temperature T_5 with

TABLE 8. OBSERVATIONS OF SECONDARY FLASH WHEN THE MUZZLE DEVICE WAS USED WITH THE CYLINDERS CUT AT AN ANGLE

	Projectile Weight (lb)				
	0.55	0.60	0.64	0.70	0.80
Ammunition Reloaded With 150 Grams HC-25-B Propellant					
Cylinder Cut at 30 deg	NF, F, F*	NF	NF	NF	NF
Cylinder Cut at 45 deg	NF, F, F*	NF			
Ammunition Reloaded With 150 Grams 8601 Propellant With 11.6 Grains K_2SO_4					
Cylinder Cut at 30 deg	NF, NF*	NF	NF	NF	NF
Cylinder Cut at 45 deg	NF, F, NF*	NF			

CODE KEY

F - secondary flash was observed
NF - secondary flash was not observed
* - 0.5 inches was added to the device's chamber length by turning ir off the threaded muzzle

FIGURE 22. COMPARISON BETWEEN PRESSURE RECORDS TAKEN AT NECK OF CARTRIDGE AND COMPUTER MATCH FOR HERCULES PROPELLANT (HC-25-B)

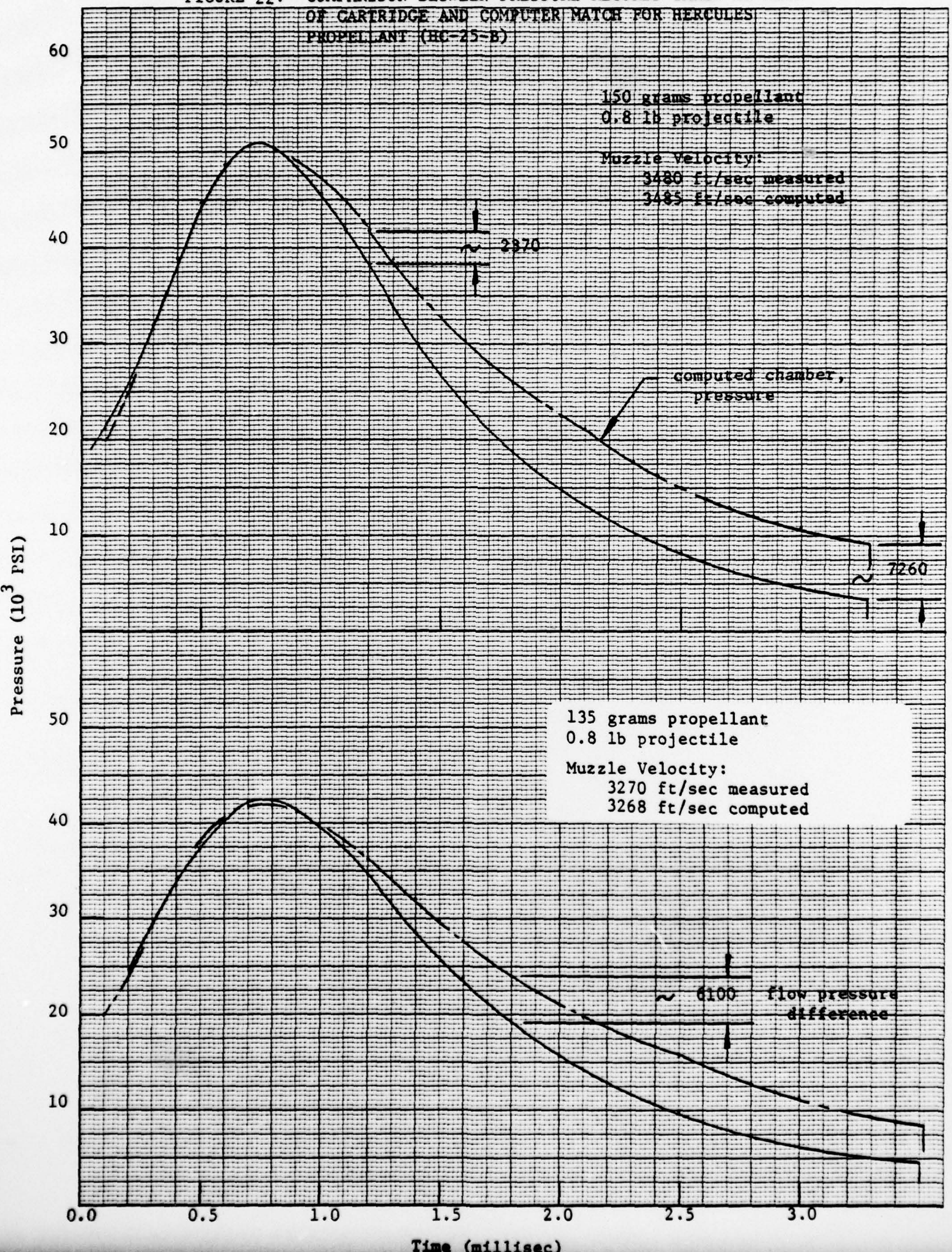


TABLE 9. COMPARISON BETWEEN COMPUTER PREDICTED AND MEASURED MUZZLE VELOCITIES FOR AMMUNITION RELOADED WITH HERCULES PROPELLANT (HC-25-B).

	Projectile Weight (lb)						
	0.80	0.74	0.70	0.64	0.60	0.55	
150 Grams Propellant Calculated Velocity (ft/sec)	3485	3554	3596	3658	3691	3720	
Measured Velocity (ft/sec)	3480	3519	3577	3633	3645	3822	3779
	3490	3510	3599	3636	3717	3772	3694
	3457	3554	3561	3619	3676	3790	3770
					3710	3698	3812
					3707	3793	3665
					3680	3776	
					3707	3734	
135 Grams Propellant Calculated Velocity (ft/sec)	3268	3325	3361	3406	3430	3459	
*Measured Velocity (ft/sec)	3277	3279	3348	3381	3402	3478	
	3270	3261	3346		3445	3434	
	3256	3315	3357		3448	3486	
			3331			3485	
120 Grams Propellant Calculated Velocity (ft/sec)	3045						
*Measured Velocity (ft/sec)	3030						

* Velocity was measured over a 2-ft course starting 17 ft from the muzzle.

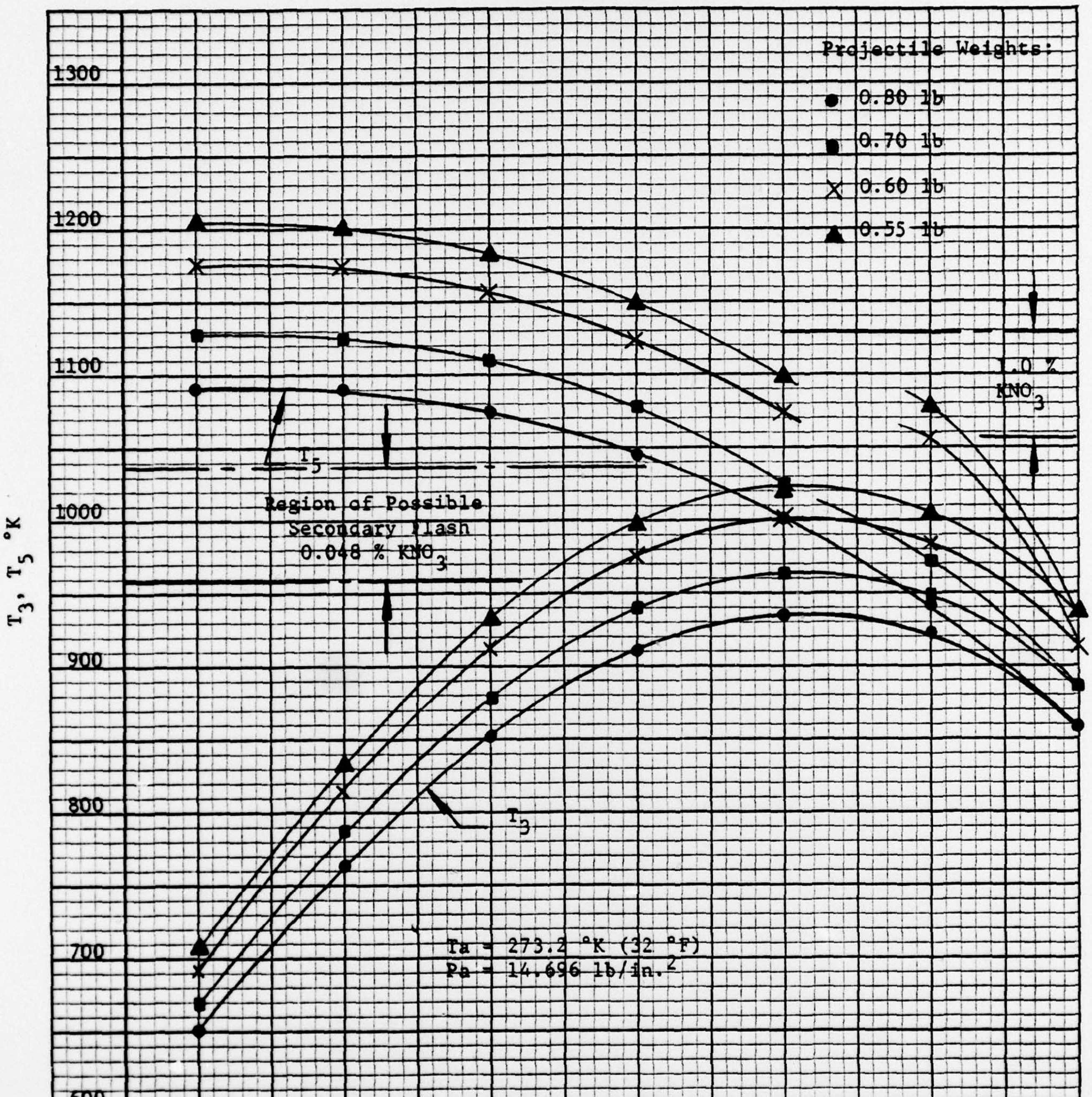


FIGURE 23. VARIATION OF TEMPERATURES T_3 AND T_5 WITH AIR MIXING RATIO FOR 150 GRAMS OF HERCULES PROPELLANT (HC-25-B) AND FOUR DIFFERENT PROJECTILE WEIGHTS

decreasing projectile weight below 0.70 lb. This discontinuity was not resolved. A comparison between the curves and the region of possible flash for 0.5 percent of suppressant salt would predict that the gun would always exhibit secondary flash based on T_5 criteria. However, the observations of Table 6 demonstrate that a projectile weight of 0.74 lb may be the critical state and this information does not fit either a T_3 or T_5 criterion for a 0.5 percent KNO_3 concentration. However, the T_5 criterion would be valid if the percent concentration of the salt were about 0.9 percent.

Figure 24 shows the change in the form of the T_3 and T_5 curves as the temperature of the gun gas/air mixture into which the gun is moving is elevated. A comparison between Figures 23 and 24 demonstrates that if the T_5 criterion is correct, as Carfagno has chosen[3], then the experimental variation in projectile weight to 0.55 lb has provided an extreme test to simulate a moving-gun gas-flow into a mixture that is almost as hot as if the gun gas were mixed only to a 50 percent concentration in non-shock manner. These conditions may not exist in the flight test and if they do occur, they would only be applicable for a brief time before the next shot was fired and not necessarily during the time immediately after the next projectile exits.

The comparison of the experimental data and the computer predictions leads to the conclusion that the propellant HC-25-B lot 021 has been successfully overtested with the muzzle device and should not exhibit SSBF in the flying GAU8/A equipped with a muzzle device incorporating the design features of the single shot device. If the propellant also has 0.9 to 1.0 percent KNO_3 content instead of the stated 0.48 percent documented concentration, then the comparison of the experimental data and computer predictions leads to further substantiation of the T_5 criteria and Battelle's computer program.

Figure 25 shows the match achieved between measured pressure/time data for the DuPont 8601 propellant with 11.6 grains K_2SO_4 mixed into the charge and the computer program.

Table 10 permits a comparison between the measured and computed muzzle velocities. In the case of this propellant the two velocities are in reasonable agreement for the 0.80, 0.74, and 0.70 lb projectiles. The

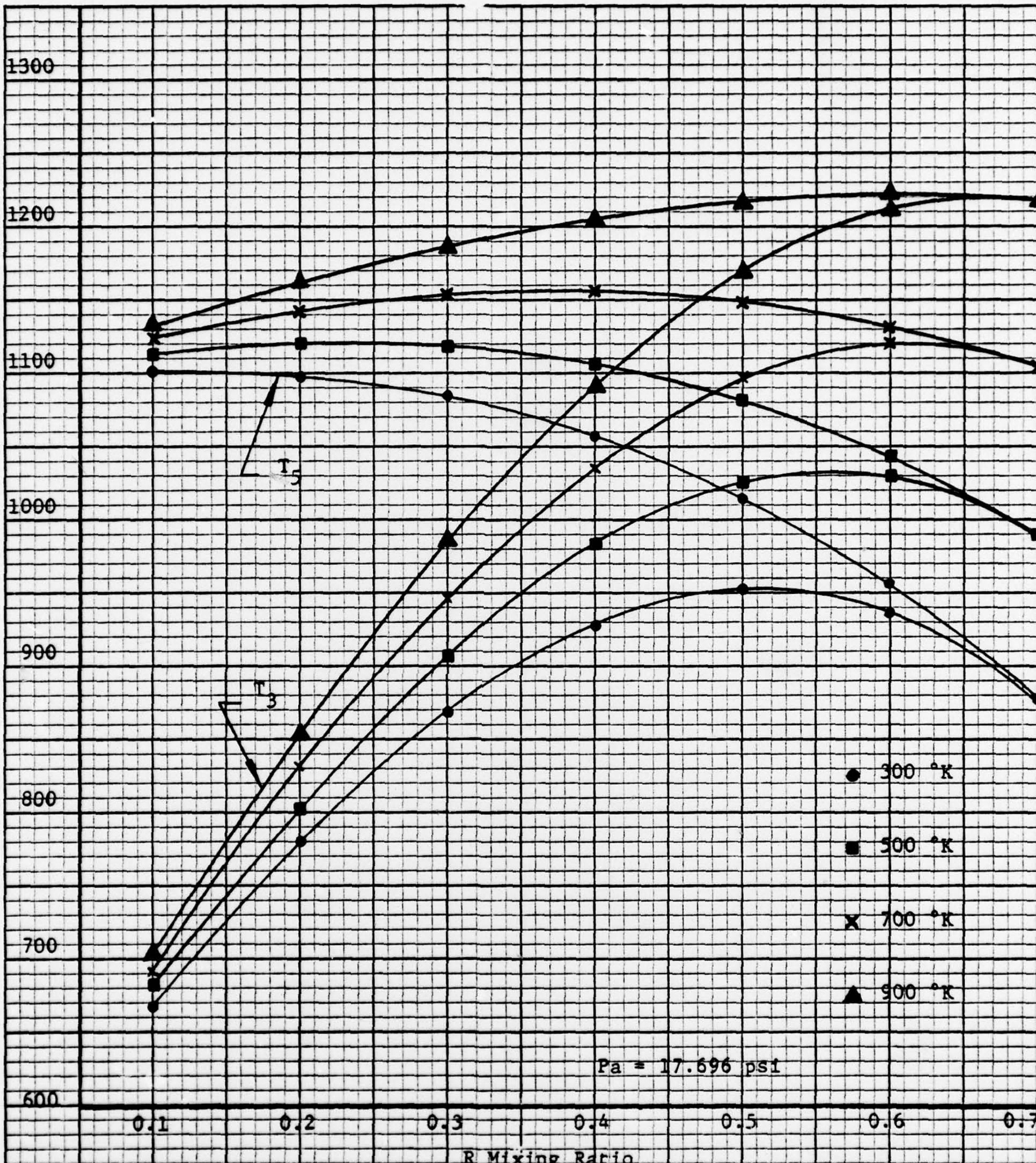


FIGURE 24. VARIATION OF TEMPERATURES T_3 AND T_5 WITH AIR MIXING RATIO AND AIR TEMPERATURE FOR 150 GRAMS OF HERCULES PROPELLANT (HC-25-B) AND A 0.8 LB PROJECTILE

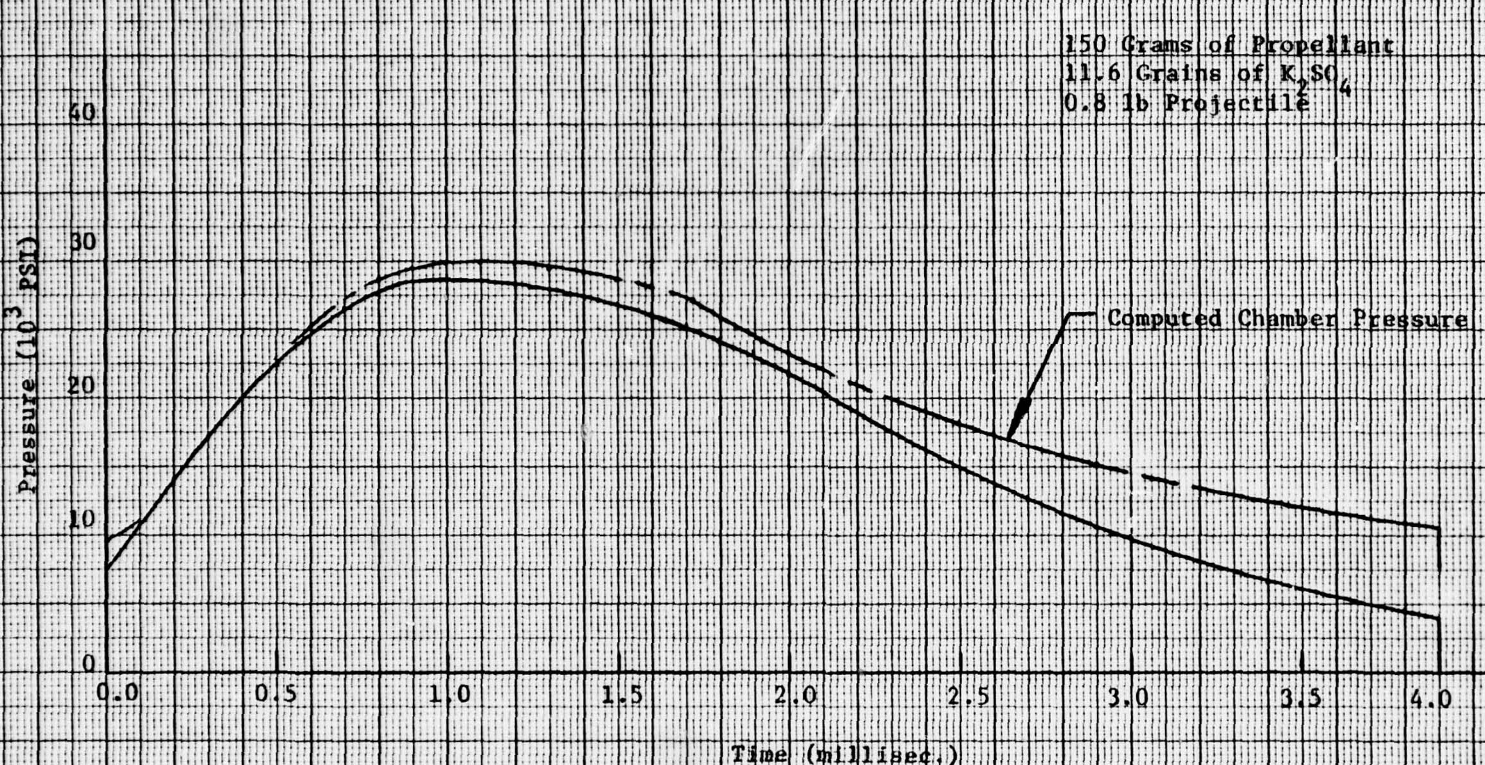


FIGURE 25. COMPARISON BETWEEN PRESSURE RECORD TAKEN AT NECK OF CARTRIDGE AND COMPUTER MATCH FOR DUPONT PROPELLANT (8601).

TABLE 10. COMPARISON BETWEEN COMPUTER-PREDICTED AND MEASURED MUZZLE VELOCITIES FOR AMMUNITION RELOADED WITH 150 GRAMS OF DUPONT 8601 PROPELLANT AND 11.6 GRAINS OF K_2SO_4.

	Projectile Weight (lb)					
Muzzle Velocity (ft/sec)	0.80	0.74	0.70	0.64	0.60	0.55
Calculated*	3167	3170	3169	3165	3162	3158
Measured	3170	3133	3171	3314	3282	3180
	3169	3142	3175	3258	3198	3279
	3210	3134	3200	3201	3287	3233
	3192	3157	3167	3186	3330	3156
	3139		3179	3264	3250	3370
	3125		3174	3184	3369	3377
	3136		3161	3175	3281	3353
			3110	3184		3323
			3110	3117		3260
			3116	3104		3212
			3137	3106		3364
				3173		3263
				3167		3381
				3130		3195
						3284
						3274
						3320
						3372
						3314
						3217
						3221
						3318
						3248
						3260

*The effect of the deterrent coating on the propellant was modelled to the pressure time curves of the 0.80 lb and the 0.70 lb projectile ballistic cycles. The pressure/time measurements for the lighter projectiles had severe pressure oscillations.

lighter projectiles show a significant amount of dispersion in the measured velocities, with the 0.64 lb projectile data providing the closest match of these to the predicted velocity. This poor comparison between the predicted and measured velocities is caused by both the computer match achieved by heavily deterring the burning rate on the surface and linearly decreasing to a depth of 0.046 inches, and the low pressures ($\sim$ 22,000 psi) measured with significant local fluctuations and cycle times.

Because of the poor propellant performance, the experimental data are very suspect as to their applicability to a moving gun using a muzzle device. However, the muzzle device was capable of suppressing the secondary flash at a 0.75 percent (17.36 grains) concentration except for the very light projectiles. It was also capable of suppressing the secondary flash when 0.5 percent (11.60 grains) of KSO_4 were used in most cases. Thus, in comparison to Figure 26, the muzzle device is probably not bringing the expanding turbulent gas flow down to the well defined T_3 curve, but it is only keeping the temperatures within the lower portion of the region bounded for possible secondary flash for 0.5 percent K_2SO_4. If the computer and experimental results can be believed, it means that the device drops the temperature expected from the T_5 curve about 100 to 120 °Kelvin. (This same temperature effect would be substantiated by the behavior of the Hercules propellant if it had 1.0 percent KNO_3 in it instead of 0.48 percent.)

CONCLUSIONS

As a result of the effort expended during this program, the five tasks stated in the Objective and Approach have been accomplished. In performing this work, the muzzle device shown in Figures 2, 3, and 4 was found to be effective in suppressing secondary muzzle flash. The computer program was matched to the performance of the supplied propellants except where these propellants performed erratically. Even then, the computer predictions are close and may be applicable.

Based upon the experimental results and the computer predictions, the muzzle device design has probably been overtested on the ground for the Hercules propellant HC-25-B lot 021; and it should successfully suppress SSBF

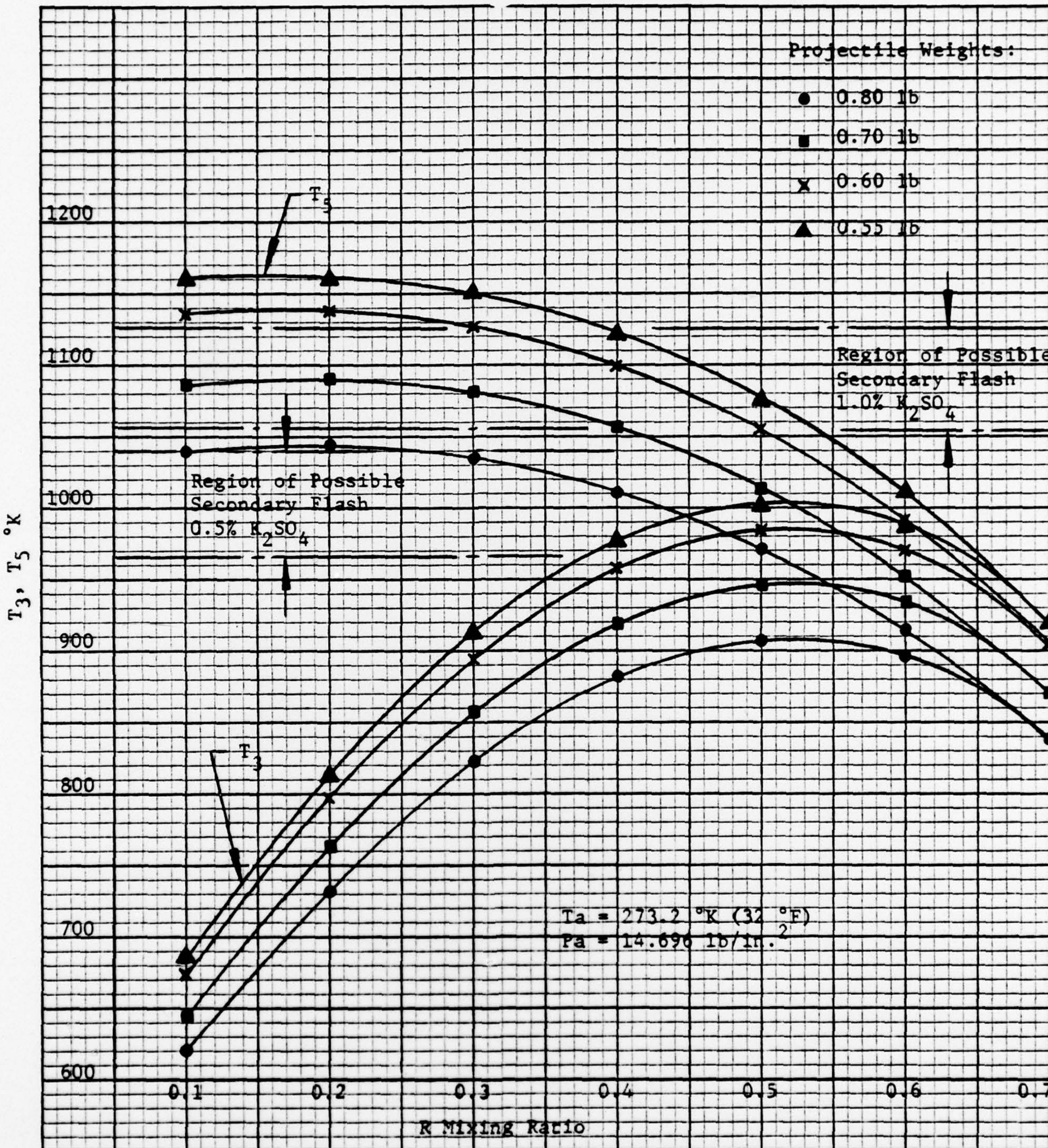


FIGURE 26. VARIATION OF TEMPERATURES T_3 AND T_5 WITH AIR MIXING RATIO FOR 150 GRAMS OF DUPONT PROPELLANT (8601) AND FOUR DIFFERENT PROJECTILE WEIGHTS

if a DuPont propellant incorporates 0.50 percent to 0.75 percent K_2SO_4 suppressant salt.

RECOMMENDATIONS

Based on the conclusions resulting from this combined analytical/experimental program, the following actions are recommended:

- A seven-barrel muzzle device incorporating the design features of the 30-mm Mann barrel device and a 45 degree central fairing should be designed and fabricated.
- The seven-barrel muzzle device should be ground tested to determine the additional recoil and side loads that will be imposed on the gun system.
- The effect of the seven-barrel muzzle device on projectile and gun system dispersion should be determined by ground testing. (A partial alternative is to determine single shot projectile dispersion using the device and a 45 degree cut cylinder on a Mann barrel.)
- The seven-barrel muzzle device should undergo ground testing with reduced weight projectiles to assist in a correlation between single shot and multiple shot muzzle device effectiveness.
- The seven barrel muzzle device should be flight tested to include some firings using reduced weight projectiles in an attempt to force a SSBF to determine the flight limit of the effectiveness of the device.

DATA ACCESSION LIST/INTERNAL DATA

The data generated under this program consist of the following:

- Monthly Progress Reports (1, 2, 3, 4, 5)
- Final Technical Report
- Experimental Records in Battelle Laboratory Notebooks Nos. 32977, 33045, 33117, 33160
- Viewgraphs for Program Review of November 30, 1976
- Drawing of the Mann Barrel Muzzle Device, No. 964-6569-1
- Collected Computer Printouts in a loose binder, no identification
- Looseleaf Book Collection of Communications and Calculations, no identification
- 16 mm Film Strips of Muzzle flashes, no identification
- 16 mm Film demonstrating the relationship between the oscilloscope records and the formation and extent of the secondary muzzle flashes.

REFERENCES

(1) Backofen, J. E. Jr., "A Brief Computer Program For Preliminary Gun Design And Prediction of Secondary Muzzle Flash", Proceedings of the 2nd International Symposium on Ballistics, March 9-11, 1976, American Defense Preparedness Association, Washington, D.C.

(2) Goddard, S., and Backofen, J. E. Jr., "An Investigation of the Secondary-Flash Problem of the GAU8/A 30-mm Gun in the A-10 Aircraft", Prepared for Fairchild Republic Company, Farmingdale, New York, by Battelle-Columbus Laboratories, Columbus, Ohio (April 11, 1975).

(3) Carfagno, S. P., "Handbook on Gun Flash", Project TAI-3603, Prepared by the Franklin Institute, Laboratories for Research and Development, Philadelphia, Pennsylvania, for Ammunition Branch, Research and Development Division, Chief of Ordnance, U. S. Army (November, 1961), AD 327 051.

(4) Young, H. H. (Editor), "Smoke and Flash in Small Arms Ammunition, 1948-1954 (U)", Prepared by Midwest Research Institute, Chemical Sciences Division, Kansas City, Missouri, for Office of the Chief of Ordnance, U. S. Army (September, 1954), AD 88 537.